Ortega, Jose Antonio

WATER REUSE POTENTIAL IN THE VALLEY OF MEXICO AND DESIGN OF A GENERAL METHODOLOGY FOR THE SELECTION OF THE BEST WATER REUSE ALTERNATIVE

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

WATER REUSE POTENTIAL IN THE VALLEY OF MEXICO AND DESIGN OF A GENERAL METHODOLOGY FOR THE SELECTION OF THE BEST WATER REUSE ALTERNATIVE

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

By

Jose Antonio Ortega

Norman, Oklahoma

1983

WATER REUSE POTENTIAL IN THE VALLEY OF MEXICO AND
DESIGN OF A GENERAL METHODOLOGY FOR THE SELECTION
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APPROVED BY

DISSERTATION COMMITTEE

ABSTRACT

The Valley of Mexico, as well as many other regions in the world, is experiencing acute water shortages mainly due to population explosion, industrial development, and limited water resources. The major objectives of this study are to develop an empirical methodology which would aid the decision-makers in the selection of the best choice water reuse alternative and to present water reuse as a viable possibility for increasing water availability in the Valley. Industrial reuse, agricultural reuse, and ground water recharge are analyzed as the most viable alternatives. The Delphi technique is utilized in this study to determine the weights of several factors involved in the decision-making process towards the selection of the best alternative choice regarding water reuse. The analysis of the responses to the questionnaires indicated that the most important decision factors to be taken into account when establishing a water reuse program are, in order of importance; public health, water quality requirements, public acceptance, operation and maintenance cost of a treatment system, water exchange, legal and institutional considerations, and capital cost of the treatment system. The results of this study show that the water supply, together with water reuse, will not be able to meet the demand unless a comprehensive water resources management program is conducted.

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ACKNOWLEDGEMENT

The author would like to express his sincere gratitude to the following persons and institutions:

Professor George W. Reid for his encouragement, guidance and support throughout the authors graduate program.

Dr. Leale Streebin, Dr. James Robertson, Dr. Robert Murphy and Dr. Alexander Kondonassis, for their comments, advice and guidance in the development of this study.

The panel experts for their contribution providing the needed information for this study.

Ms. Wilma Clark for typing the draft and final copy of this dissertation.

The Consejo Nacional de Ciencia y Technologia of Mexico for its helpful financial support.

The family of the author, his mother Emilia R. de Ortega, his father Aniceto Ortega Espinosa, and specially his wife Monica for their encouragement and support.

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CHAPTER I

INTRODUCTION

General

As Mexico achieves greater degrees of development, the need for implementing wastewater treatment systems becomes of extreme importance, not only for pollution control purposes but to serve as a means for water supply augmentation. The situation of the Valley of Mexico is such that the water supply cannot meet the demand mainly because of a rapid increase in population and industrial growth.

The Valley of Mexico is located at the southern end of the central Mexican Plateau, with an approximate area of 9600 square kilometers at a height of 2240 meters above sea level. (See Figure 1.1). Different terms are used to refer to urban areas within the Valley of Mexico. The Federal District consists of sixteen delegations. The metropolitan area of Mexico City includes the Federal District and twelve neighboring municipalities in the State of Mexico. And finally the Valley of Mexico includes portions of the Federal District, the State of Mexico, Hidalgo, Tlaxcala and Puebla. (See Figure 1.2).

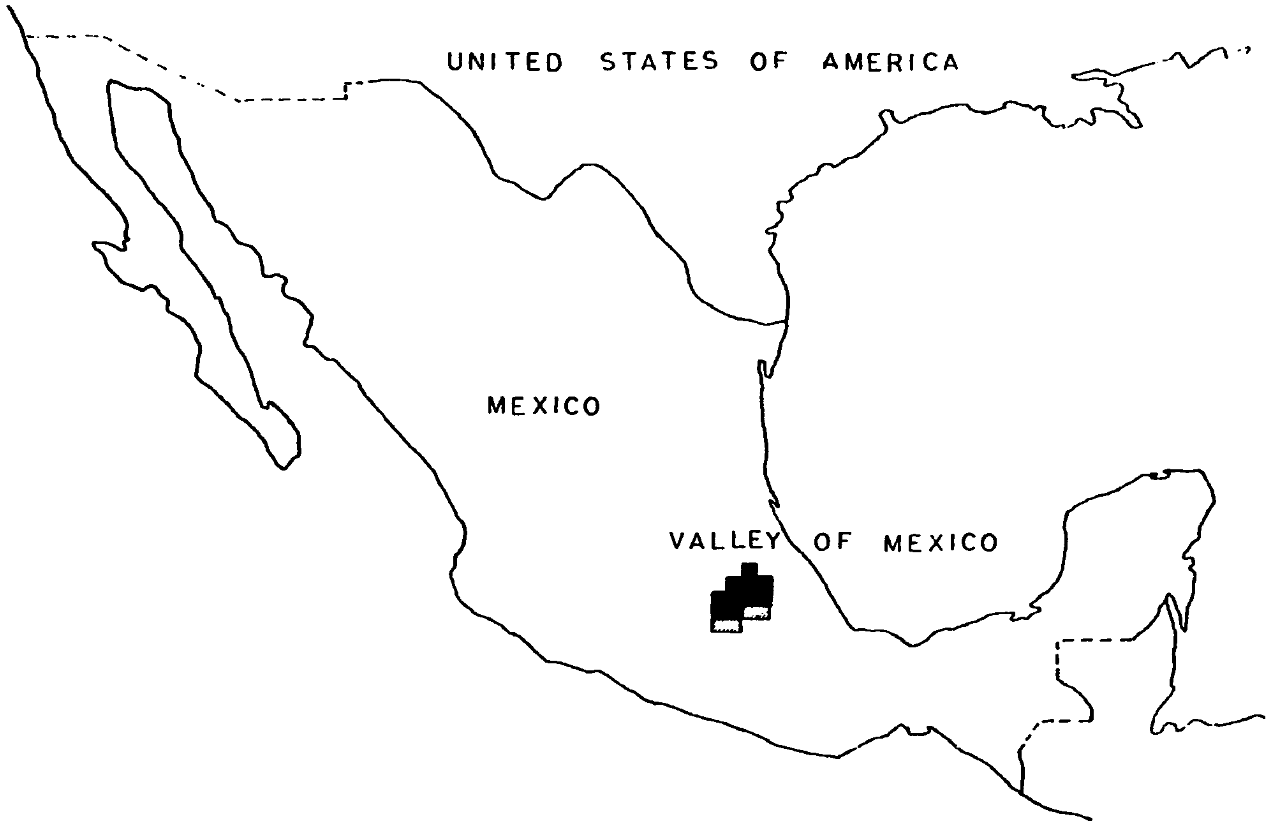


Figure 1.1. Geographical Location of the Valley of Mexico.

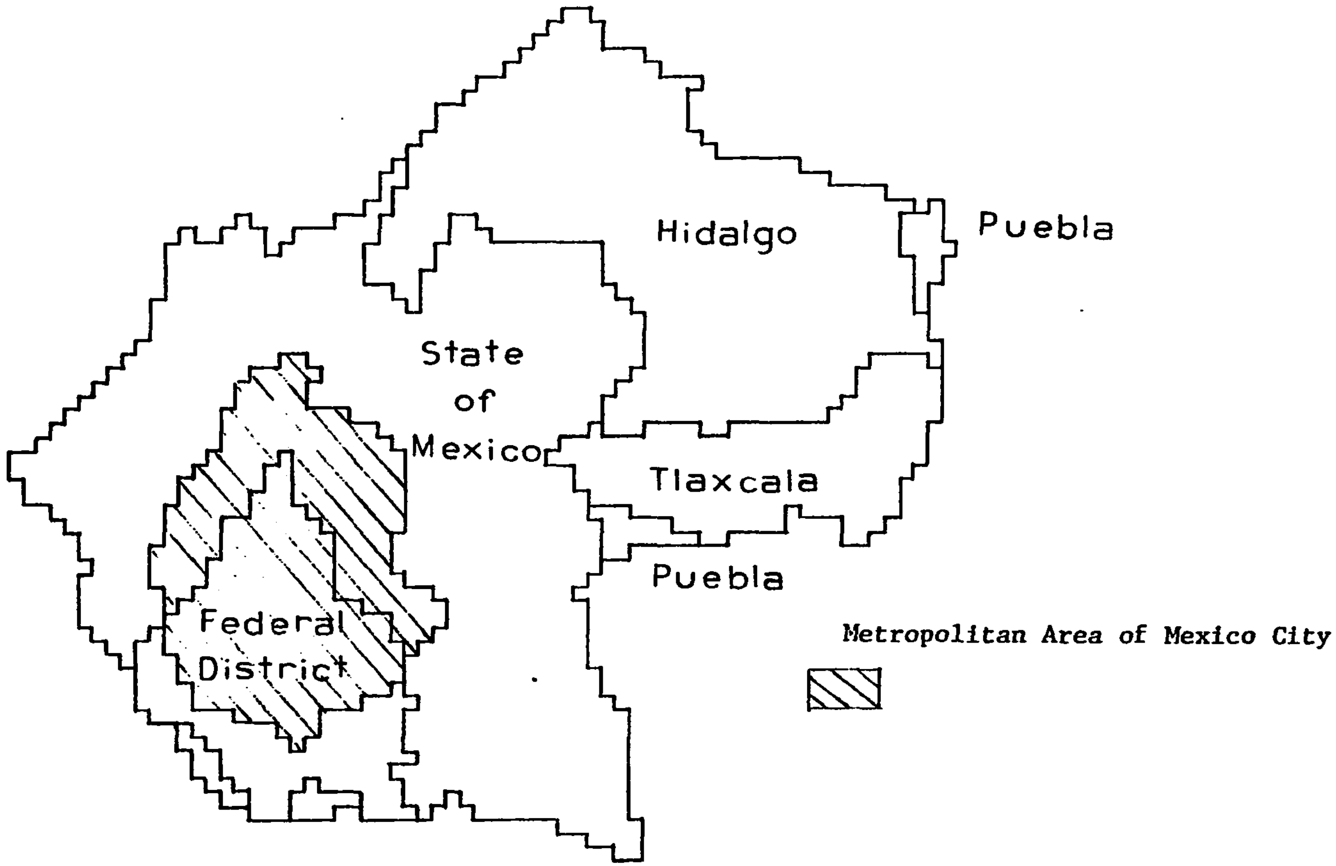


Figure 1.2. States Which Integrate the Valley of Mexico

Since the first settlements were established in the Valley, water has become a very important resource. At the time of the Aztecs, great hydraulic works were built with the purpose of bringing water to the city and alleviating flooding problems during the rainy season. In the 16th century the Texcoco lake system disappeared. By the 19th century surface water sources were tapped by increasing settlements and as the city grew, urbanization also tapped underground sources of water, limiting the amount of water that could be recharged into the aquifer. In 1942, the need for interbasin water transfer arose; therefore, efforts were made to transfer water from the springs of the Lerma river. By the end of the 1940's, water wells had to be drilled at the Lerma catchment basin because the springs that once served as a water source had already dried. Today, water is being transferred from the Cutzamala river as well as from the Lerma basin.

Currently, only a very small fraction of the wastewater produced in the valley is reused after being treated. The first effort for using reclaimed water began about 1954, with the wastewater treatment plant located in Chapultepec Park. The water obtained from this plant and from all others which were later developed is used to keep levels in lakes and for landscape irrigation.

A few industries have built their own wastewater treatment facilities for reuse purposes; unfortunately, these efforts have not been sufficient to account for a considerable portion of the wastewater produced in the Valley.

In the selection of the best alternative choice for water reuse, several factors are taken into account in the decision-making process, factors such as the public health aspects, the water quality requirements, the possibility for water exchange between users, the capital cost of a treatment system, the operation and maintenance cost, the legal and institutional considerations, and the public acceptance.

The Problem

The Metropolitan Area of Mexico City has experienced in recent years a very rapid growth, due mainly to population increase and industrial growth. Based on figures from the Consejo Nacional de Poblacion, three alternative population estimates for the Valley of Mexico in the year 2000 are presented according to three different hypotheses. The first considers the goals set by the National Plans for a population of 25,400,600. The second considers historical growth rates and a population of 37,346,000, and the third considers no change in social growth and a decline in natural growth according to national goals for a population of 28,904,300. According to the National Plan for Industrial Development, the expected industrial growth in the Valley is 2.5 percent annually up to the year 2000. The great demand for water in the Valley of Mexico, together with the limited water resources in the area, creates a situation in which the water supply is not able to meet the demand. The recharge capability of the aquifer has been seriously diminished by uncontrolled urban growth. Therefore, the aquifer of the Valley is being overexploited, causing a deterioration of the water quality, a sinking of the city up to eight meters in some places and ruptures in distribution and sewer lines.

The topography of the Valley also poses several problems. The Valley is located at 2240 meters above sea level and is enclosed by mountains making the access to neighboring water sources very difficult and costly. Implementing any type of water reuse plan for the Valley of Mexico requires a systematic approach in the selection of a best choice water reuse alternative. At present no model or systematic approach has been considered in the few water reuse programs that have been implemented.

The Objectives

The major objectives of the study are to develop an empirical methodolgy which would aid decision-makers in the selection of a best choice water reuse alternative and to present water reuse as a viable possibility for increasing water availability in the Valley by indicating the uses and volumes that could be reclaimed.

Other objectives intrinsic in the major objective are:

1. To conserve high-quality water supply for uses that require such quality
2. To expand opportunities for population, industry and agriculture
3. To reduce costs in carrying out water management programs to supply the Valley with sufficient water

Assumptions

The study considers assumptions dealing with Mexican reality in the economic, technical, and social fields. It is conducted in general terms because specific applications of reclaimed water require detailed study.

One of the main limitations in conducting the analysis is the insufficiency and unreliability of information generated by different agencies in the Mexican government. This situation leads to the establishment of educated assumptions to compensate for information deficiencies.

Some general assumptions are presented in the following lines:

- Regulations will allow water reuse in those instances when it is socially acceptable and technically and economically feasible.
- Opportunity costs in neighboring basins will further limit the amounts of water that could be transferred to the Valley.
- Water users will be charged the real cost of water, without any subsidies by the government.
- Run-off from agricultural use will not be considered available for reuse.
- Water reuse for domestic consumption will not be considered feasible at this time.
- The factors to be considered in the decision-making process for the selection of the best available reuse alternative will be the following: public health aspects, water quality requirements, water exchange, capital cost of treatment

system, operation and maintenance cost, legal and institutional considerations, and public acceptance.

CHAPTER II

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

Introduction

Water reuse has been practiced in Mexico for many years. The most widely spread application is the irrigation of agricultural land. In order to implement water reuse programs, some factors have to be present: water supplies must be limited; water supplies of good quality must be limited due to pollution; new water supplies must be developed for greater distances at a higher cost to the community; and wastewater treatment facilities must be built to meet discharge requirements. In the case of the Valley of Mexico the factors mentioned above are at present suggesting the need for a realistic water reuse program in the valley. In order to have a common frame of reference, it is essential to define the terms and concepts that will be used throughout this study. (See Glossary)

Most of the water reuse conducted in Mexico is indirect. In this study the potential uses to be considered for reuse are industrial, agricultural, and ground water recharge. The later, however, is generally not regarded as a use but a means of augmenting the water supply. The sources of wastewater that are utilized for reuse purposes are the three conduits that drain the Valley. Mainly the Gran Canal del

Desague which carries most of the wastewater during the dry season, the Emisor Poniente and the Emisor Central (See Figure 2.1)

Culp[1] indicates that in the United States, of the total water reused, 62 percent is used for irrigation, 32 percent for industry, and 5 percent for ground water recharge.

As the cost of providing fresh water for the Valley is escalating, the authorities cannot afford to do nothing to augment the total available supply by means of water reuse. The conservation of high quality sources can be achieved by means of source substitution with reclaimed water.

Each potential use of reclaimed water has its specific water quality requirements. Therefore, it is not possible to establish definite requirements, but it is possible to establish them in general terms and according to past experiences some ranges and limitation in selected parameters.

Industrial Reuse

The main industrial applications for reclaimed water are: cooling, boiler feed, and process water. These applications require water of diverse qualities, cooling water being that which requires a lower quality and process water being that which requires a higher quality in most cases.

In determining the feasibility of water reuse in industry, several factors have to be considered such as: 1) cost of water available to industry; 2) water quality requirements; 3) cost of treating wastewater and 4) regulations governing water discharge.[2]

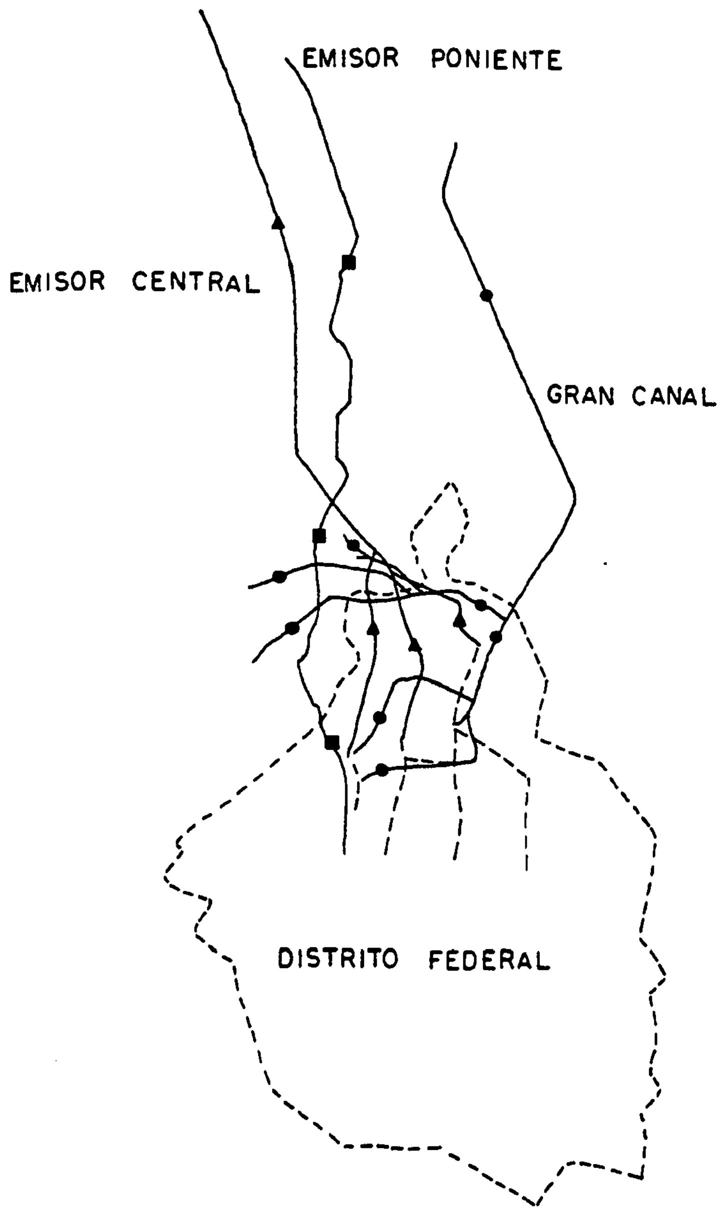


Figure 2.1. Conduits Draining the Valley of Mexico.

The use of reclaimed domestic sewage in industry presents several advantages such as: low treatability requirements, constant composition and dependable flow. In the United States, 358 locations reuse water for different industrial applications, cooling being the most widely spread.[3]

Presently, in the Valley of Mexico only a few industries reuse water. The total flow that is being reused is approximately 1.5 meter cube per second which is only a small amount of the 40.0 generated in the valley.[4]

In Mexico, cooling water accounts for approximately 70 percent of all the water intakes in the manufacturing industry. For this use, the most important parameters that have to be closely monitored are suspended solids, pH, and nutrients.[5] Several power plants in Nevada, Texas, California, and Colorado utilize treated municipal wastewater for cooling purposes with satisfactory results.[6] Boiler feed water in general should be free of suspended solids and low in dissolved oxygen, calcium, and magnesium. As boiler pressure increases, the quality of the water required increases; therefore, further treatment is needed.[7] Process water quality depends on the type of industry. Due to a wide range in equipment and plant processes, it is difficult to determine in general terms the most important parameters, but in most cases high quality water is required.

Industry in the Valley of Mexico has registered in the last 15 years an annual growth rate of 8.1 percent. This rate has led to the concentration in the valley of 43.6 percent of the total manufacturing industry of the country.[8] The industrial groups that consume

71 percent of the total industrial water supply in the valley are: pulp and paper, chemical products, food products, textiles, iron and steel, and non-metalic minerals.[9] These industries are located mainly in five industrial zones; Ecatepec, Cuautitlan-Lecheria, Tlanepantla, Naucalpan and Valleyo.

The criteria for establishing water quality requirements in industry depend on the specific use that this water is subject to . Three major industrial uses are cooling water, boiler feed, and process water.

Cooling water quality requirements are based on the criteria that water must not corrode, plug equipment, or create scale problems. Cooling water quality can be divided to serve two purposes, once through and make up water. (See Table 2.1) The criteria for establishing water quality requirements for boiler make up water is based on the operating pressure of the boiler system. (See Table 2.2)

Agricultural Reuse

Land application of wastewater is the oldest method of sewage treatment. Water reuse in agricultural irrigation serves two purposes; the first is that wastewater is subject to a land treatment process through the plants and the soil. The second is that wastewater serves as a source of moisture and nutrients for the growth of crops, especially in areas where water is scarce.

Approximately 8 meter cube per second of raw wastewater is now being used to irrigate 18,000 hectares in the Valley of Mexico.[10] These waters are applied to the soil without any prior treatment in

Table 2.1

Cooling Water Quality Requirements

Selected Parameter (mg/l)	Cooling Water: Once through	Cooling Water: Make up
Calcium	500 - 1,200	500 - 1,200
Iron	1.0 - 14.0	1.0 - 80.0
Manganese	0.02 - 2.5	0.02 - 10.0
Dissolved Solids	1,000 - 35,000	1,000 - 35,000
Suspended Solids	250 - 5,000	250 - 1,500
Chemical Oxygen Demand	- -	100 - 200
Temperature ^{o}C	37	48

Source: Gordon Culp, George Wesner, Robert Williams, and Mark V. Hughes, Jr., Wastewater Reuse and Recycling Technology, Pollution Technology Review, No. 72, Park Ridge, New Jersey: Noyes Data Corporation, 1980, p. 101.

Table 2.2

Boiler Water Quality Requirements

Selected Parameter (mg/l)	Boiler Make up Water: 0 to 1,500 psig	Boiler Make up Water: 700 to 5,000 psig
Iron	10	10
Manganese	80	80
Dissolved Solids	35,000	35,000
Suspended Solids	15,000	15,000
Chemical Oxygen Demand	100	500
Temperature ^{o}C	48	48

Source: Gordon Culp, George Wesner, Robert Williams and Mark V. Hughes, Jr., Wastewater Reuse and Recycling Technology, Pollution Technology Review, No. 72, Park Ridge, New Jersey: Noyes Data Corporation, 1980, p. 101.

zones located mainly north of the metropolitan area. Utilizing the effluent after treatment of the wastewaters from the metropolitan area of Mexico City to irrigate crops in the Valley would be a valuable asset for local farmers. The crops produced in the Valley are legumes, alfalfa, barley, beans, corn, wheat, pears, apples, figs, peaches.

The climate of the Valley is very stable with a mean annual temperature of 17.5^{o}C and most of the rainfall during the summer months.

The soil in the Valley consists of loam-sandy soil, clay, sand, gravel, volcanic bowling, tezontle with lapilli, ash with lapilli, lime stone and basalt.

The type of wastewater treatment necessary to be able to apply reclaimed water to agricultural land depends on the type of crop, the soil characteristics, and the quality of the wastewater.

The most important water quality parameters to monitor in waters that are to be used for irrigation are: salinity, sodium, iron, toxic materials, organic matter, suspended solids, nutrients, and pathogenic organisms.[11]

The criteria utilized in determining the water quality requirements for agricultural irrigation are related to soil crop relationship as well as health considerations. (See Table 2.3) These recommended concentrations are for unrestricted irrigation and continuous use on all soils. The most relevant factors to be considered in agricultural application of wastewater are the long term effects on the soil, and the effect of microorganisms on human health.

Table 2.3

Agricultural Irrigation Water Quality Requirements

Selected Parameter (mg/1)	Agriculture Irrigation
Arsenic	0.1
Fecal Coliform (MPN/100 ml)	1,000
Boron	1.25
Chromium	0.1
Iron	5.0
Lead	5.0
pH	6.0 - 9.0
SAR	26
Total Dissolved Solids	700
Zinc	2.0

Source: Gordon Culp, George Wesner, Robert Williams and Mark V. Hughes, Jr., Wastewater Reuse and Recycling Technology, Pollution Technology Review, No. 12, Park Ridge, New Jersey: Noyes Data Corporation, 1980, p. 78, 227.

Ground Water Recharge

Ground water recharge is a direct means for water supply augmentation. It has been practiced in the Valley of Mexico on a very limited scale, utilizing only rain water. In most cases, the sites have been closed mainly due to urban growth and pollution.[12] At present, several ground water recharge sites are being considered for possible recharge projects.

The steadily declining aquifers in the Valley of Mexico severely threaten water availability of good quality, at a time when there is a lack of areas with surplus water for inter-basin transfers at reasonable costs.

In general, two methods are utilized in ground water recharge: 1) percolation, and 2) injection. These methods require water of different quality in order not to pollute the aquifer. Lower quality water is needed when the percolation method is used, because the ground acts as a filter where natural soils absorb pollutants introduced with the water and breaks them down by a process similar to self-purification occurring in lakes and water courses. Among the most important parameters to be monitored when recharging the aquifer are coliform counts and toxic materials.[13]

Groundwater in order to be utilized as a source of public water supply must meet potable water requirements after disinfection. Regarding surface spreading and injection as means of ground water recharge, it is recognized that surface spreading and percolation does not appear to cause harmful effects on the ground water basins, as long as the municipal sewage has not been affected by industrial discharges. Direct injection requires that the quality of the water to be injected meet public water supply requirements. Because of the high level of treatment required for injection recharge, it will not be considered at this time as a viable means of ground water recharge.

Water Demand

The rapidly increasing water demand in the Valley of Mexico suggests a need for seeking alternative means for developing additional water. Currently this Valley demands approximately 58.5 meter cube per second of which 53 percent is used for domestic purposes; 12 percent is used in industry; 11 percent is used in commerce and services; 9 percent is utilized in public uses; and 15 percent is used in agriculture.[14] (See Figure 2.2)

The per capita water consumption in the Valley varies from 50 to 450 liters per day.[15] On the average the per capita water consumption is considered in this study to be 300 liters per day. The growth of the industrial, agricultural, and municipal sectors in the Valley of Mexico depends heavily on an adequate water supply. Water reuse, together with water conservation, is considered in this study as the most viable alternative in order to maintain some level of growth in the Valley.

The population of the Valley of Mexico in 1980 was 15,445,000. It is estimated that the population of the Valley may grow according to one of three alternatives studied by the Consejo Nacional de Poblacion. (See Table 2.4) The graphical representation of the population figures is shown in Figure 2.3.

The estimates of future water requirements for the Valley of Mexico are based on the average per capita water consumption and the population estimates. (See Table 2.5) The graphic representation of these figures is shown in Figure 2.4.

It is very difficult to estimate future water requirements for specific uses; therefore, it is assumed that the water use will remain in the same proportions as it is today.

The water rates for 1981 utilized in the Distrito Federal for households that have water meters are shown in Table 2.6.

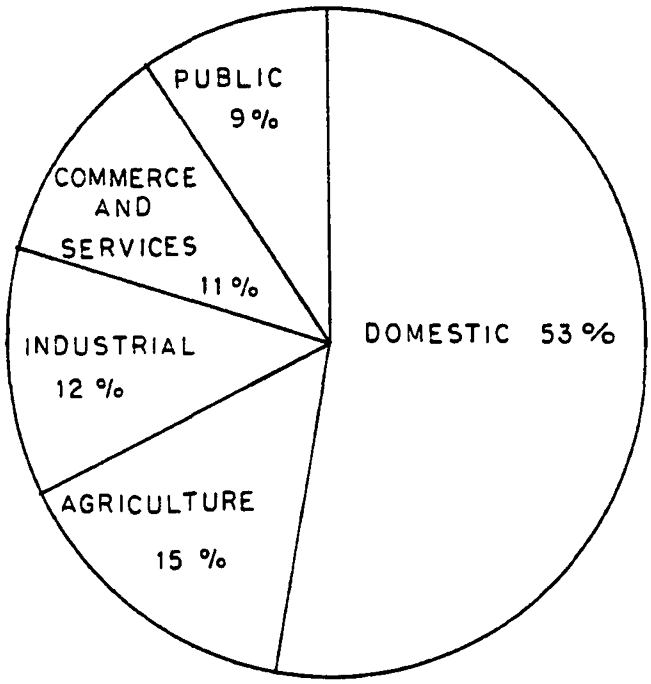


Figure 2.2. Water use in the Valley of Mexico.

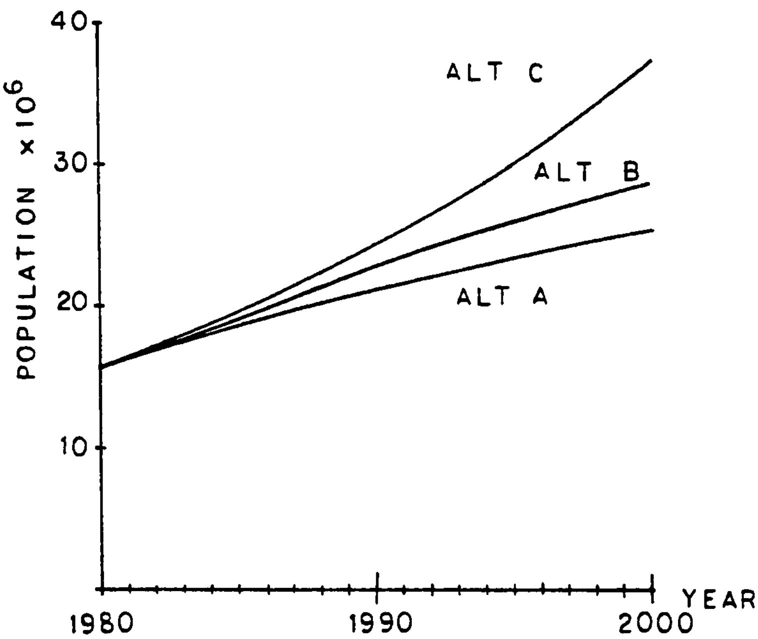


Figure 2.3. Population Projections for the Valley of Mexico.

Table 2.4

Population Estimates for the Valley of Mexico

Year	Population X 10^3		
	Alternative A[a]	Alternative B[b]	Alternative C[c]
1980	15,445.0	15,445.0	15,445.0
1982	16,778.8	16,874.1	17,025.6
1988	20,167.5	21,216.7	22,418.8
1994	22,982.6	25,345.1	28,979.8
2000	25,400.6	28,904.3	37,346.0

Source: Estimates based on projections for the metropolitan area of Mexico City (made by the Consejo Nacional de Poblacion) and for the rest of the Valley, 1982.

[a]Alternative A considered the goals set by the National Plans.

[b]Alternative B considered no change in social growth and a decline in natural growth according to National goals.

[c]Alternative C historical growth rates.

Table 2.5

Water Requirements for the Valley of Mexico

Year	Demand (m^3/Sec)		
	Alternative A	Alternative B	Alternative C
1980	53.6	53.6	53.6
1982	58.2	58.6	59.1
1988	70.0	73.7	77.8
1994	79.8	88.0	100.6
2000	88.2	100.4	129.7

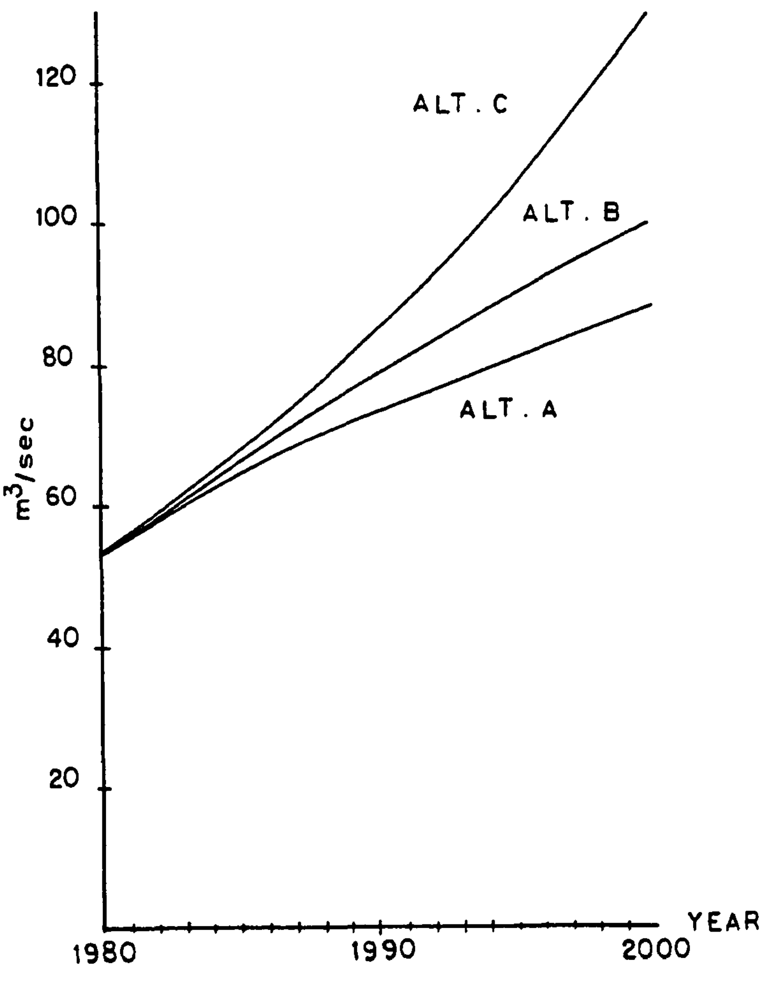


Figure 2.4. Estimated Water Requirements for the Valley of Mexico.

Table 2.6

Water Prices in the Distrito Federal

Volume (m^3)	Price per m^3 [a] (dollars)
Up to 60	fixed amount[b]
Up to 100	$0.0093
Up to 125	0.0133
Up to 150	0.0167
Up to 200	0.0233
Up to 300	0.0300
Up to 400	0.0367
Up to 500	0.0433
Up to 750	0.0467
more than 750	0.0693

Source: Departamento del Distrito Federal, Tarifas, 1981.

[a]Prices in dollars at an exchange rate of 150 pesos to the dollar.

[b]$0.40 per a two month period.

For cases where no water meter exists the water rates are shown in Table 2.7.

Water Availability

The mean annual precipitation in the Valley of Mexico is 700 millimeters, which is equivalent to approximately 213 meter cube per second of which 23 are estimated to recharge the aquifer and 3 are stored as surface water. The rest of the run-off is discharged through the Valley's drains.[17]

Table 2.7

Water Prices

Diameter of Delivery Pipe (mm)	Price per two month period (dollars)[a]
Up to 13	$ 1.33
Up to 19	26.66
Up to 26	40.00
Up to 32	60.00
Up to 39	73.00
Up to 51	100.00
Up to 64	180.00
Up to 76	273.33

Source: Departamento del Distrito Federal, Tarifas, 1981.

[a]Prices in dollars at an exchange rate of 150 pesos to the dollar.

The amount of water currently being supplied to the Valley is approximately 58.7 meter cube per second.[18] This includes water available in the Valley and water being transferred from other basins. (See Table 2.8) The geographical location of the current sources of water supply to the valley are shown in Figure 2.5.

The only surface water in the Valley is run-off water that is stored in small reservoirs. The volume of superficial water available amounts to approximately 3 meter cube per second. At present, no specific plans have been formulated to construct new reservoirs.

Most of the water available in the Valley is ground water; approximately 23 meter cube per second is the actual recharge capacity

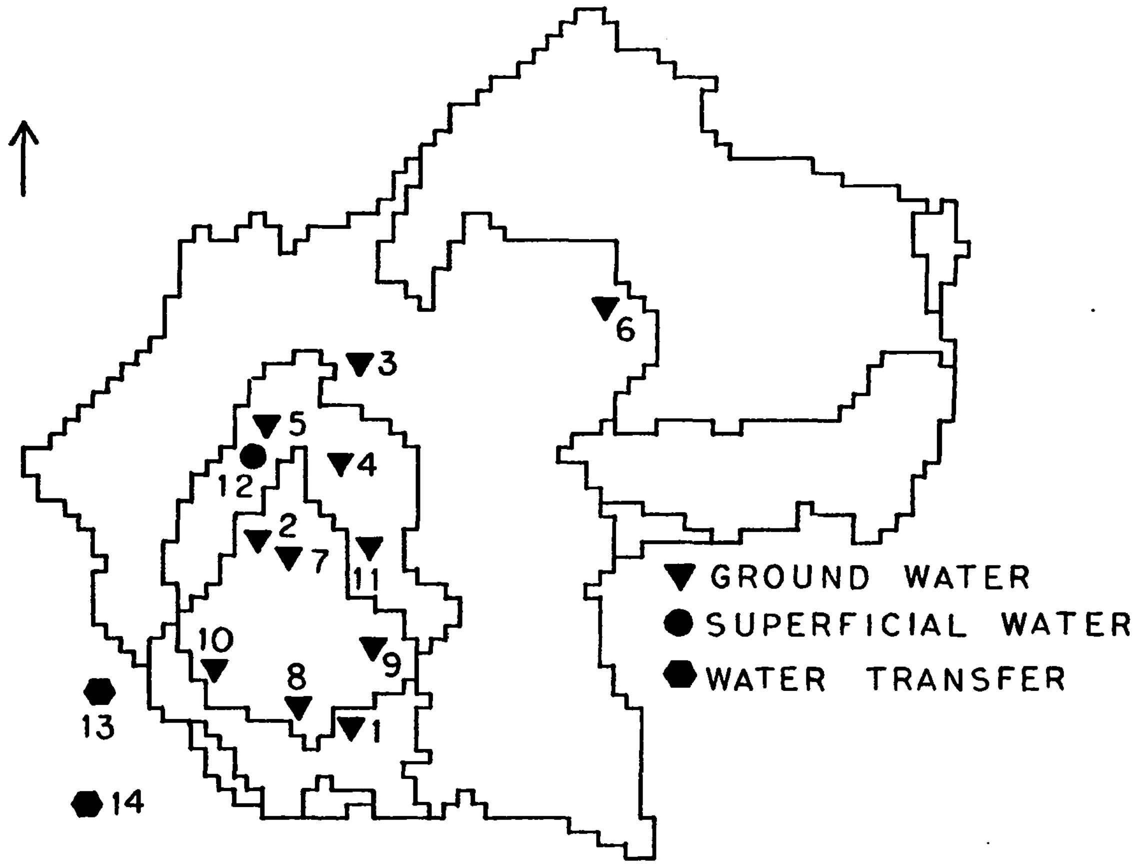


Figure 2.5. Sources of Water Supply for the Valley of Mexico.

Table 2.8

Sources of Water Supply for the Valley of Mexico

No		Yield (m^3/Sec)
1	Xochimilco	5.0
2	Municipal Wells (Federal District)	4.5
3	Los Reyes	3.7
4	Chiconautla	3.5
5	Cuautitlan	3.3
6	Apan	3.0
7	Private Wells (Federal District)	2.5
8	Pozos Sur	2.5
9	Chalco	2.5
10	Manantiales Poniente	0.8
11	El Penon	0.5
	Public Wells (State of Mexico)	4.4
	Private Wells (State of Mexico)	2.5
12	Guadalupe	3.0
13	Lerma	12.0
14	Cutzamala	4.0
	Total	58.7

of the aquifer.[19] Although the water being extracted from the aquifer amounts to 40 meter cube per second, the quantity of water that is considered available without affecting ground water quality is the recharge capacity.

Plans are underway to reduce ground water extraction by 2 meter cube per second each year from 1980 until 1990. This plan will reduce over-exploitation of the aquifer and will preserve water of adequate quality to serve as public water supply.

Two large water supply projects have been implemented to being water to the basin of the Valley of Mexico. One is the Lerma project, which supplies the Valley with 12 meter cube per second, and the other is the Cutzamala project, which in its initial phase is supplying 4 meter cube per second. The cost of these projects has been extremely high, due mainly to the distance that water has to be transported, and the high energy consumption of pumping the water to the Valley at 2240 meters above sea level. (See Figure 2.6)

The Cutzamala project in its final phase in 1990 is designed to supply 22 meter cube per second. At present, work on the second phase of the project is suspended due to economic problems.

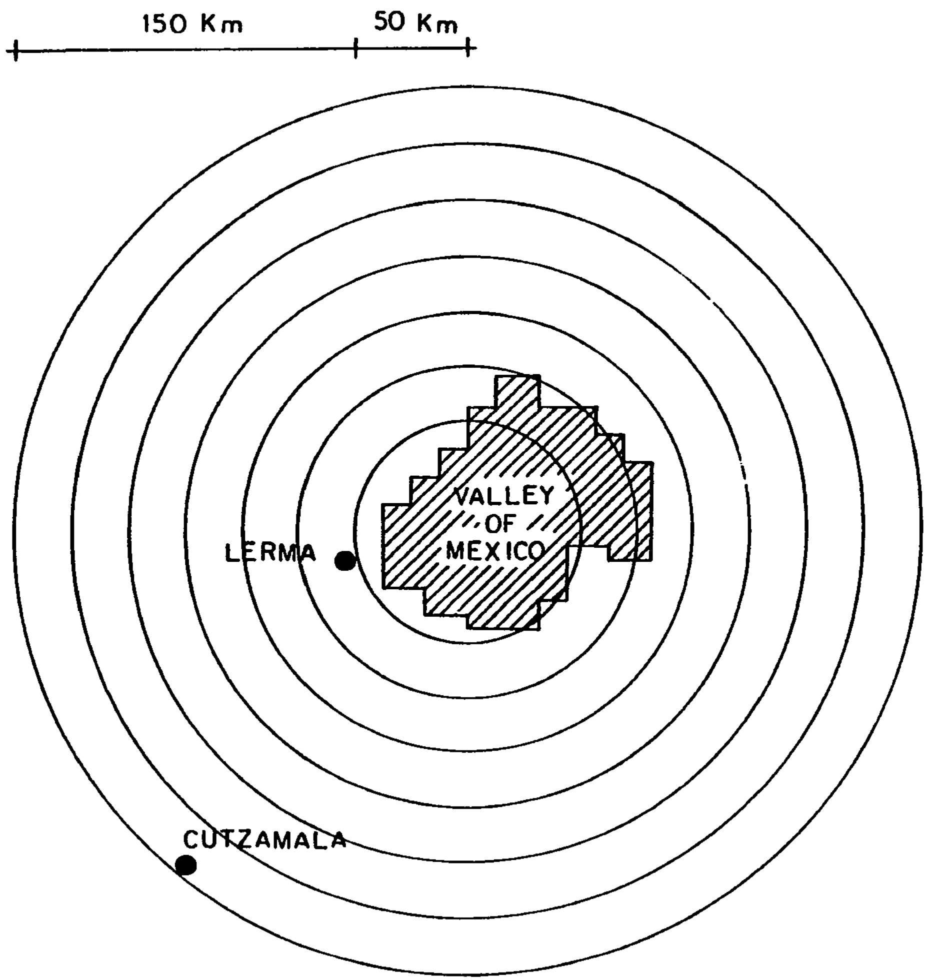


Figure 2.6. Interbasin Water Transfer Projects for the Valley of Mexico.

CHAPTER III

WATER REUSE POTENTIAL

Introduction

Water reuse is only a part of a comprehensive program that has to be implemented in the Valley of Mexico in order to satisfy future water requirements. This study concentrates on water reuse as a means of increasing water supply.

A comprehensive water resources management program for the Valley would have to include several policy alternatives directed towards meeting future water supply needs. These alternatives are presented in the following paragraphs.

In general terms, two broad approaches can be identified, the first consisting of a more rational use of existing water supplies, and the second an increase of water supplied to the Valley.

A more rational use of existing supplies can be achieved by a reduction of the water demands by means of education directed towards conservation, realistic water prices, metering of water users, and water restrictions. Reduction in water losses and waste can also aid reducing water demand; these reductions can be achieved by means of elimination of leaks, and water saving devices.

An increase of water supplied to the Valley may be accomplished by interbasin water transfers, development of new surface water, ground water, and water reuse.

The alternatives mentioned above are not always fully applicable in the Valley, and no single alternative would be able to solve future water needs.

The major impediments to the implementation of specific water reuse projects in the Valley of Mexico are: the continued subsidies of water that, unless modified, will make the implementation of any reuse project very unlikely; and the lack of guidelines referring to potential users, guidelines which will be necessary for the adequate implementation of reuse projects.

The potential water reuse in the Valley of Mexico can be determined by identifying potential reclaimed water users as well as the quantity and quality of wastewater available for reuse.

Potential Users of Reclaimed Water

This study considers three uses as the most relevant towards determining water reuse potential in the Valley of Mexico. These are industrial use, agricultural use, and ground water recharge. In the following paragraphs a description of the situation regarding each one of these users in the Valley is presented.

The number of industries established in the Valley of Mexico amounts to 31,612.[20] These industrial establishments vary in size and type of industry. The Valley accounts for approximately 43.6 percent of the total manufacturing industry of the country. Of the total industrial water demand in the Valley, 81 percent is allocated in six industrial groups.[21] (See Table 3.1)

Industries are disseminated in the Valley in seventeen zones consisting of different types of industrial groups. Each zone demands water proportionally to the number of its industries, their size, and their type. (See Table 3.2)

Table 3.1

Industrial Water Demand

	Percent
Pulp and Paper	26
Chemical Products	21
Food Industry	8
Textiles	3
Iron and Steel	10
Non-Metalic Minerals	13
Other Industries	19

Souce: Comision de Aguas del Valle de Mexico, "Estudio de la Demanda y Posibilidades de Reuso de Agua en la Industria Establecida en el Area Metropolitana de la Ciudad de Mexico," SRH, 1979, p. 16.

Presently, the industrial water demand in the Valley amounts to 11 meter cube per second, which is mainly distributed in the industrial zones. In the future, industrial growth is expected to slow down according to the National Plan for industrial development.

The industrial zones have the possibility of expanding are those which have land availability. These are Ecatepec, Cuautitlan - Lecheria, Tlanepantla, Iztapalapa, Cerro de la Estrella, Coyoacan, and Coapa. (See Figure 3.1)

Table 3.2

Industrial Zones and Their Contribution to the Total Industrial Water Demand

No		Percent
1	Ecatepec	19.4
2	Cuautitlan - Lecheria	9.1
3	Tlanepantla	7.3
4	Iztapalapa and Cerro de la Estrella	2.1
5	Coyoacan and Coapa	4.0
6	Vallejo and Azcapotzalco	23.3
7	Naucalpan	9.0
8	Xochimanca and Nonoalco	3.3
9	Gustavo A. Madero and Tepeyac	7.1
10	Lomas and Observatiorio	0.3
11	Merced Balbuena	0.4
12	Granjas Mexico and Agricola Oriental	0.1
13	Granjas San Antonio and Progreso del Sur	2.1
14	Nicolas Romero	1.6
15	La Paz	1.2
16	Ixtapaluca	6.0
17	Tlalmanalco	3.7

Source: Comision de Aguas del Valle de Mexico, "Estudio de la Demanda y Posibilidades de Reuso de Agua en Industria Establecida en el Area Metropolitana de la Ciudad de Mexico." SRH, 1979, p. 18.

At present only 1.5 meter cube per second is reused in industry, which amounts to 14 percent of the total industrial demand. The potential for increasing this percent is very high due to the fact that the manufacturing industries require large amounts of cooling water, between 50 and 81 percent of their total water used, which is equivalent to 6 and 9.7 meter cube per second respectively.[22]

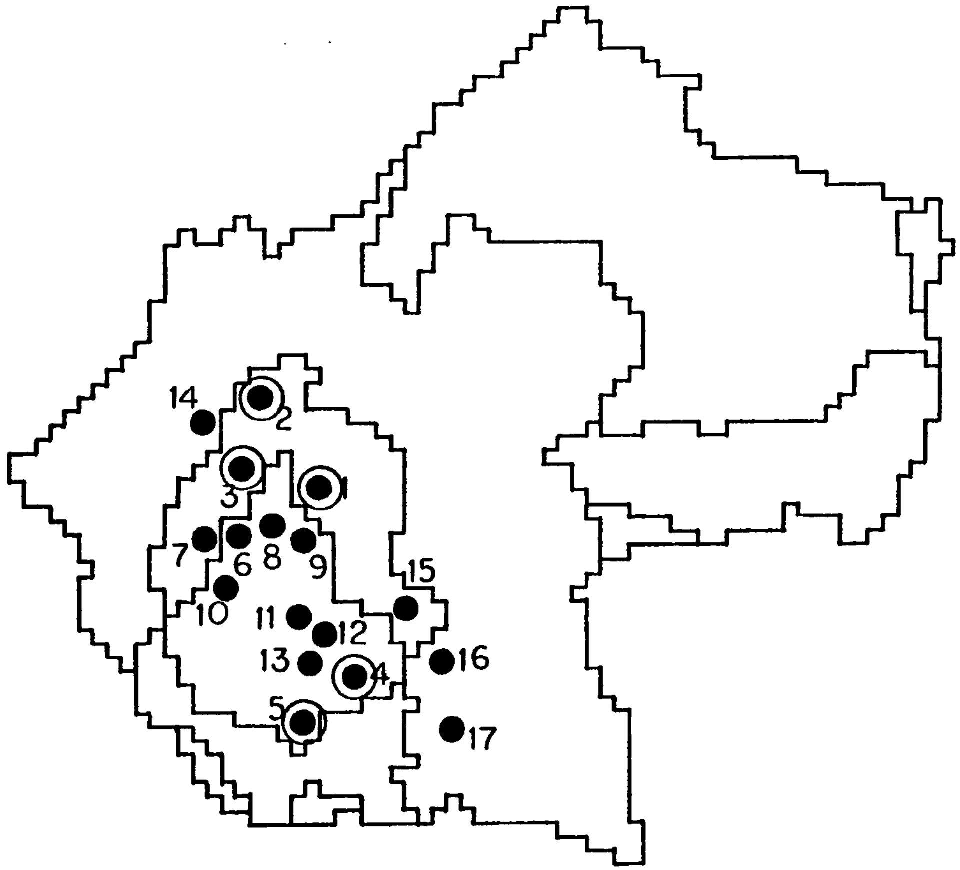


Figure 3.1. Industrial Zones in the Valley of Mexico.

The location where industrial reuse is potentially feasible are the industrial zones previously identified. Because of the limited water resources, no additional zones will be considered in the future.

Industrial water reuse in the Valley would require wastewater of mainly domestic origin, which would be subject to secondary treatment as a minimum requirement.

Agricultural irrigation in the Valley of Mexico by means of wastewater spreading has been practiced since 1900.[23] This irrigation has been carried out mainly north of the Metropolitan Area, and without any treatment prior to its application.

Today 8.4 meter cube per second is used in agriculture irrigation in the Valley, and it is estimated that 8 meter cube per second of wastewater is utilized to irrigate 18,000 hectares in the Valley. This means that of the total irrigation requirements 95 percent is satisfied by wastewater. It is important to point out that this water is not treated previous to its application.

The current irrigation practice with untreated wastewater has brought obvious benefits to the agriculture production of the area. At the same time the possible harm to the population exposed indirectly or directly to pathogenic organisms in the wastewater, as well as the exposure to toxic compounds which can result in harm to human health, damaged crops, changes in soil characteristics, and pollution of the ground water, has not been evaluated.

The salinity of the wastewater is one of the most important considerations prior to application. Different plant species have different tolerance to salinity concentrations, most fruits have low

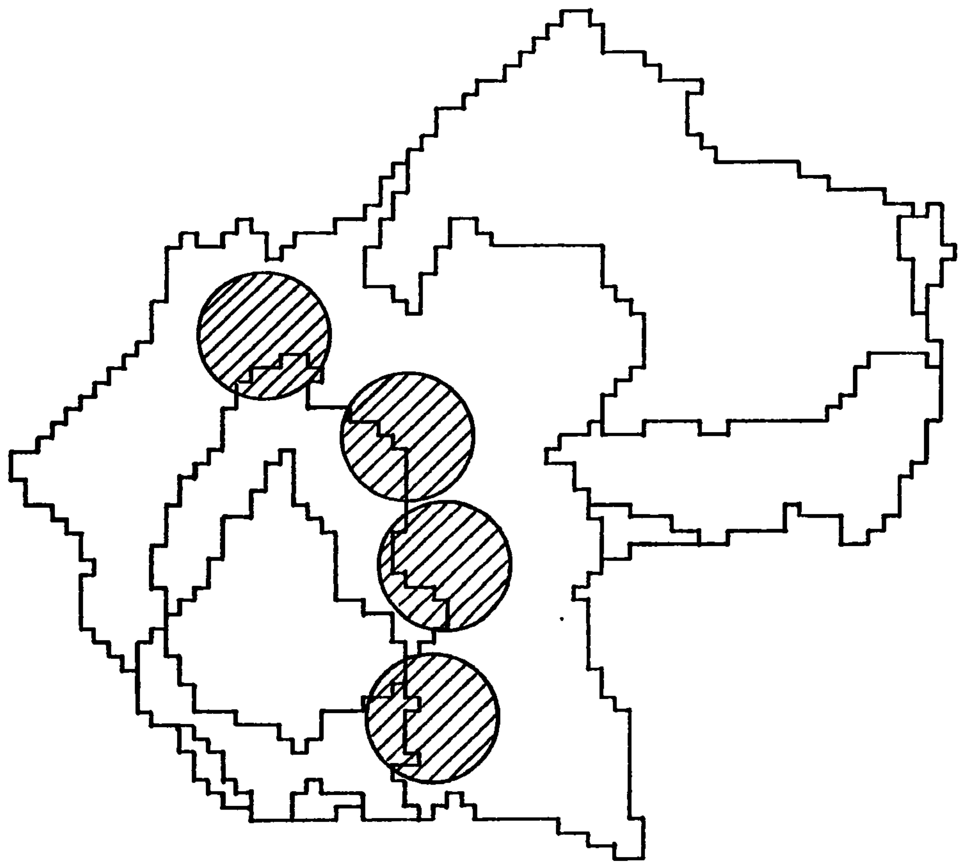


Figure 3.2. Existing and Potential Agricultural Irrigation Zones.

salt tolerance, most vegetable crops as well as forage and field crops have medium salt tolerance.

In the future agricultural irrigation in the Valley of Mexico is expected to increase with the opening of new irrigation zones. (See Figure 3.2) These potential irrigation zones would amount to 28,000 hectares in addition to the 18,000 already used.

In the Valley of Mexico several ground water recharge projects have been implemented, but most of them have been cancelled because of urban growth or pollution. All of the projects so far that have been implemented have used rain water as their source. Currently only one recharge project is in operation, the Xictli pilot project.

A great potential for ground water recharge exists in the Valley. The selection of recharge sites is essential for the implementation of a well designed program. The criteria utilized for the selection of recharge sites includes the following:

- source of recharge water
- geological formation
- chemical characteristics of the native water in the aquifer
- retention time of recharge water in the aquifer
- topography
- availability of land

Surface wastewater spreading appears to be the most suitable recharge method for the Valley because of the low treatment requirement. The following purification process occurs during wastewater spreading; percolation through the Aerobic zone of soil, uptake or nitrogen, phosphorus and other substances by crops or vegetation, filtration and adsorption in the soil above the aquifer, and bacterial and chemical reactions. The applied wastewater is treated as it flows to the aquifer. Organics are reduced substantially in the top soil due to biological oxidation. Filtration occurs through the soil. Nitrogen is removed by crop uptake, and phosphorus is removed by adsorption and chemical precipitation.

Source controls for toxic compounds would greatly aid the application of wastewater. At present, the area located in the Eastern sector of the Federal District seems to be appropriate for ground water recharge. The sites considered as potential recharge areas are Santa Catarina and Milpa Alta. (See Figure 3.3)

Extensive geological studies are required in the Valley of Mexico, as well as the implementation of pilot projects which would prove the feasibility and value of full scale ground water recharge projects.

Regionalization of the Valley

The population density in the Valley of Mexico varies considerably. It is very low in the northeastern corner of the Valley and very high in downtown Mexico City with 25,000 people per square kilometer.

The regionalization of the Valley is based on the level of urbanization, the level of industrial activity, and the availability of hydraulic infrastructure. (See Figure 3.4)

Region I is located in the Southeastern sector of the Federal District. Its level of urbanization is low as well as the number of industries in the area. The hydraulic system covers a small portion of this area.

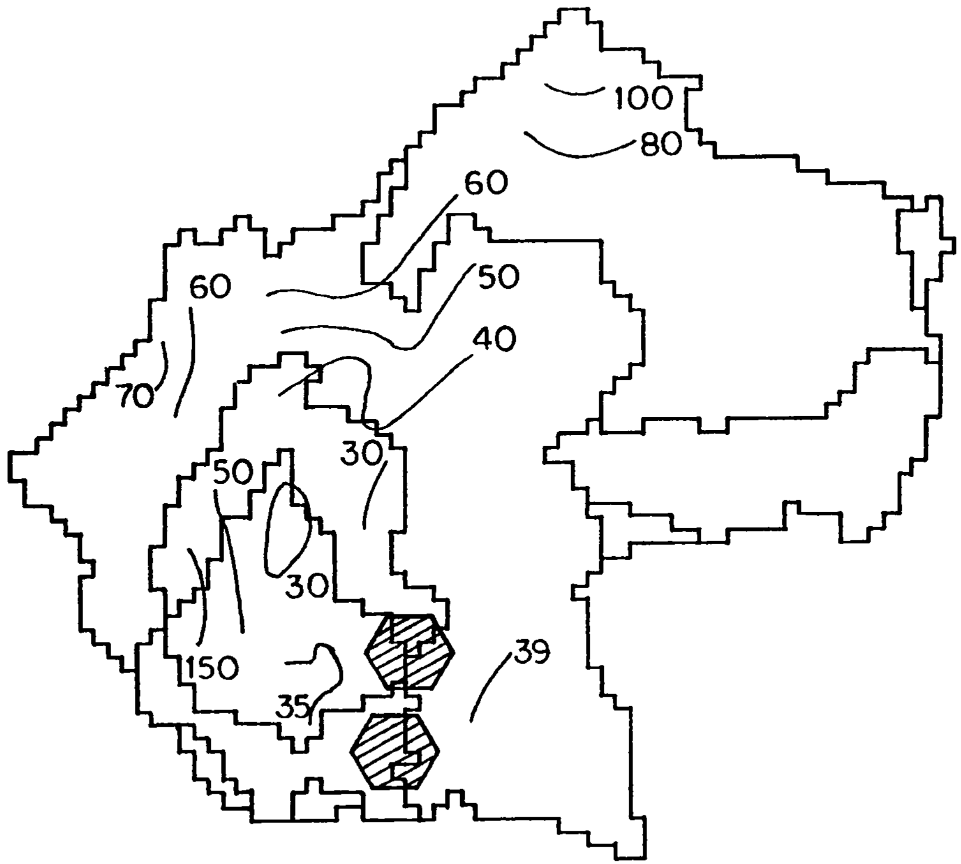


Figure 3.3. Potential Ground Water Recharge Sites.

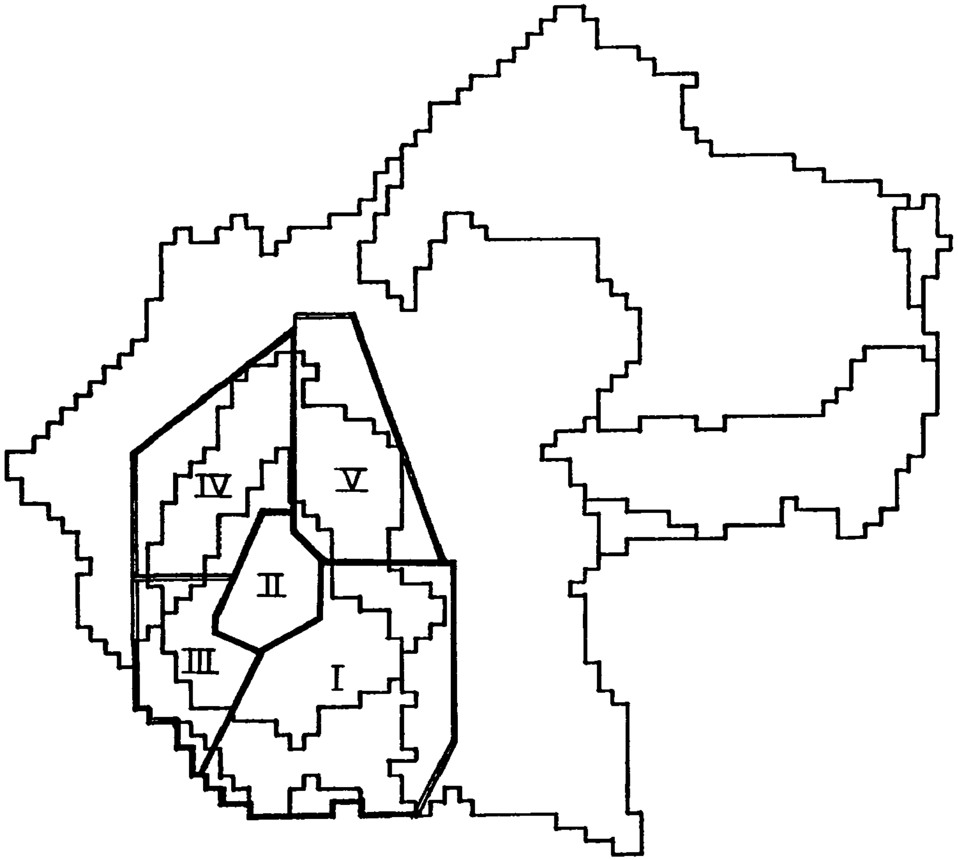


Figure 3.4. Regionalization of the Valley of Mexico.

Region II is located in downtown Mexico City. Its level of urbanization is very high, with only a few industries in the area. This Region is completely covered by the hydraulic infrastructure.

Region III is located on the Eastern sector of the Federal District. Its level of urbanization is low with medium industrial participation. The hydraulic system covers a small portion of this area.

Region IV is located Northwest of the Federal District. Its level of urbanization is high as is its level of industrialization. The coverage of the hydraulic system is medium.

Region V is located Northeast of the Federal District. Its level of urbanization is low, with medium industrial participation. The coverage of the hydraulic system is low.

Table 3.3

Regionalization of the Valley

Region \ Variable	URBANIZATION	INDUSTRIALIZATION	HYDRAULIC COVERAGE
I	L	L	L
II	H	L	H
III	L	M	L
IV	H	H	M
V	L	M	L

H = High M = Medium L = Low

The Regionalization of the Valley is directed towards facilitating the analysis of potential users of wastewater because if thse users and the source of wastewater are not near each other, bringing water from the source to the point of reuse would neither be convenient nor economical.

Potential Sources of Wastewater

The source of wastewater considered in the study is the collection system that carries the wastewater of a specific region in the Valley. These sources indicate the quantity of wastewater potentially available for reuse. Actual measurements of the quantity of wastewater discharged have not been conducted; therefore, this quantities are estimated. The volume collected by the system varies considerably because the storm and sanitary sewers are not independent. The estimates of the amount of water collected by the system during low flow are based on an average per capita water consumption of 300 liters per capita per day, an average water loss of 20 percent, an average amount of people with sanitary sewer service of 70 percent, and the population distribution in the Valley. (See Table 3.4)

Table 3.4

Wastewater Availability

Region	Flow (m^3/Sec)
I	3.02
II	9.05
III	3.92
IV	7.84
V	6.34
Total	30.17

Approximately 31 percent of the total population of the urbanized areas of the Valley of Mexico does not have sanitary sewer service. This situation indicates that only part of all wastewater generated in the Valley is collected and potentially reusable. From the estimate presented above 30.17 meter cube per second is the total volume collected during low flow. The metropolitan area of Mexico City has a combined type sewage system, therefore during the rainy season the volumes of wastewater together with storm water amount to flows much larger than the minimum flow estimated for the dry season. Three main conduits that drain the Valley are the Gran Canal del Desague, the Emisor Poniente and the Emisor Central.

The potential for reuse of the wastewater available also depends on the quality of the wastewater and the potential uses that it may serve.

Wastewater Quality

The quality of the wastewater generated in the Valley varies from region to region according to the types of industries and the ratio of industrial to domestic wastewater.

The minimum and maximum concentrations recorded of a selected group of parameters as well as the concentrations recorded at the Gran Canal from October 1975 to February 1976 are presented in Table 3.5.

It can be expected that the higher concentrations of some parameters be found in the most industrialized zones in the Valley such as is the case of region IV.

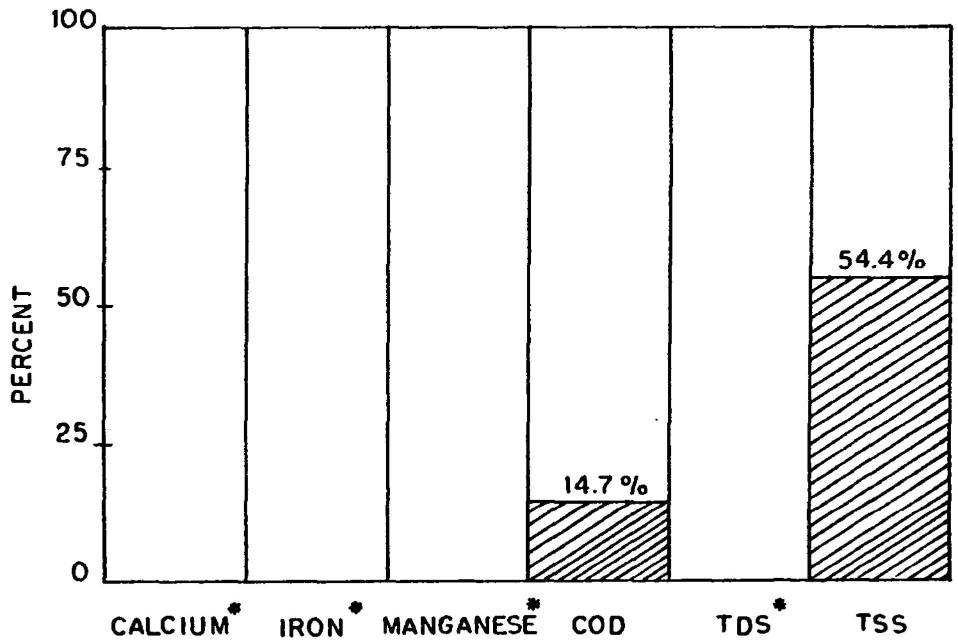
Table 3.5

Wastewater Characteristics

Parameter	Concentration		
	Min	Gran Canal	Max
Biochemical Oxygen Demand	110	246	746
Chemical Oxygen Demand	120	546	1,356
Total Suspended Solids	78	107	2,755
Total Dissolves Solids	392	-	2,510
PH	6.0	7.45	7.5
Fecal Coliforms (10^6 Orgs/100 ml)	17.0	-	197.25
Arsenic	0.019	0.022	0.170
Boron	1.89	2.83	25.6
Iron	0.9	4.05	50.5
Lead	0.018	0.1712	0.190
Manganese	0.060	0.32	0.860
Sodium	52.8	330	435.2
Zinc	0.028	0.089	4.23

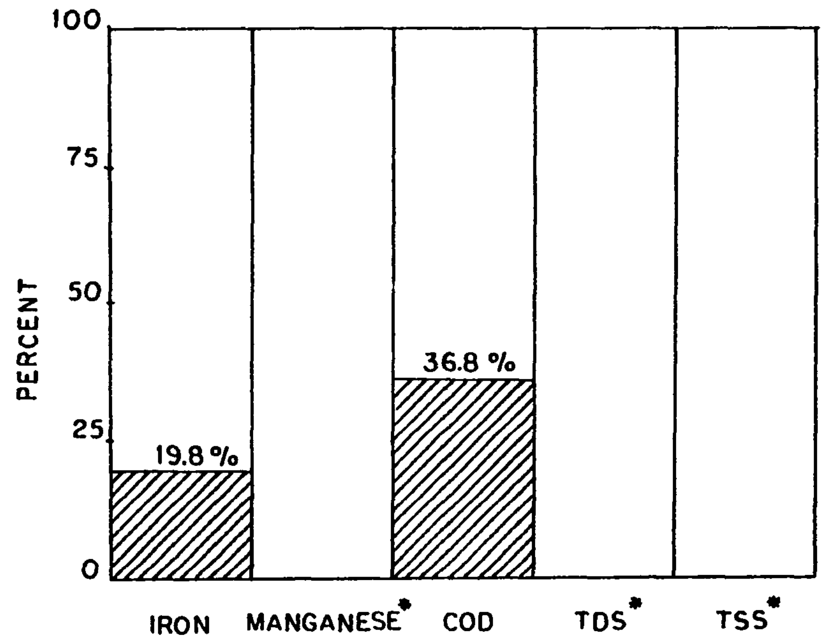
Source: S.A.R.H. "Evaluacion del Impacto Ambiental del transporte y uso de las Aguas Residuales del Area Metropolitana del Valle de Mexico en la Agricultura." Mexico 1980 and D.D.F. "Mexico City's Master Plan for Reuse", Water Reuse Symposium II, August 23-28, Washington, 1981.

A comparative analysis of the water quality requirements for the different uses considered in this study and the quality of the wastewater available in the Valley of Mexico is presented in Figures 3.5, 3.6 and 3.7. This analysis indicates the maximum concentrations recorded and compares them to water quality requirement for each specific use, showing that some constituents require removal to the extent that is indicated in the Figures.



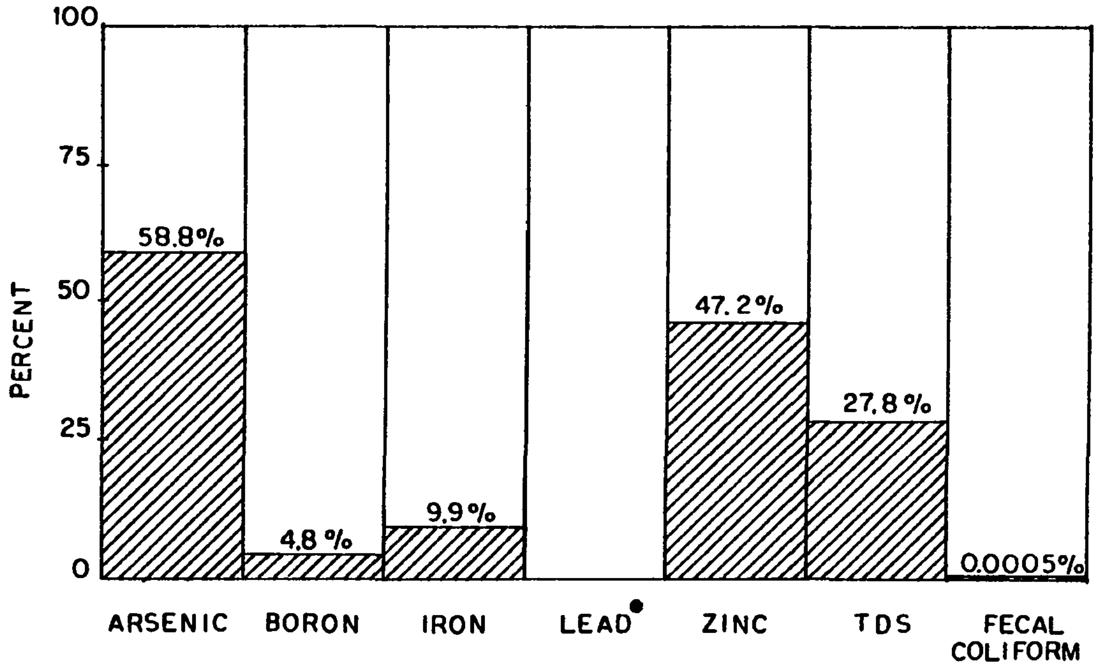
*The concentration of this parameter in the wastewater never exceeds the required concentration for this use.

Figure 3.5. Comparative Analysis of Cooling Water Quality Requirements and Maximum Concentrations Recorded in the Wastewater of the Valley of Mexico.



*The concentration of this parameter in the wastewater never exceeds the required concentration for this use.

Figure 3.6. Comparative Analysis of Boiler Make up Water Quality Requirements (700 to 5,000 psig) and the Maximum Concentrations Recorded in the Wastewater of the Valley of Mexico.



*The concentration of this parameter in the wastewater never exceeds the required concentration for this use.

Figure 3.7. Comparative Analysis of Agricultural Irrigation Water Quality Requirements and Maximum Concentrations Recorded of the Wastewater of the Valley of Mexico.

Reclaimed Water Distribution

This section consists of the distribution of available wastewater to the identified potential users of reclaimed water. Estimated quantities of reclaimed water are allocated to the different zones based on average reuse capability of industries in the Valley and agricultural irrigation requirements.

Region I. The Region has ground water recharge capabilities, potential for agricultural irrigation of fourteen hectares, and seven industrial zones.

The total amount of wastewater available in the Region is 3.02 meter cube per second. This water can be distributed within the Region, mainly in the industrial zones (See Table 3.6), and the remaining in agricultural irrigation and ground water recharge.

Table 3.6

Industrial Zones Located in Region I

Zone	Reuse Potential (m^3/sec)
Iztapalapa and Cerro de la Estrella	0.161
Coyoacan and Coapa	0.308
Granjas Mexico and Agricola Oriental	0.007
Granjas San Antonio and Progreso del Sur	0.161
La Paz	0.092
Ixtrapaluca	0.462
Tlalmanalco	0.284
TOTAL	1.475

The Region would use 1.475 meter cube per second in industry and 1.545 in agricultural irrigation and ground water recharge. The total reuse potential of this Region is 3.02 meter cube per second.

Region II. The Region has no potential for agricultural irrigation and ground water recharge. The potential of this Region lies with industrial reuse.

The total amount of wastewater available in the Region is 9.05 meter cube per second. The wastewater available exceeds by far the potential for reuse; only two industrial zones are located in the Region. (See Table 3.7)

Table 3.7

Industrial Zones Located in Region II

Zone	Reuse Potential (m^3/sec)
Xochimanca and Nonoalco	0.254
Merced Balbuena	0.030
TOTAL	0.284

The Region would use 0.284 for industrial reuse. The remaining wastewater available could be utilized in another Region. The total reuse potential of this Region is 0.284 meter cube per second.

RegionIII. The Region has no potential for agricultural irrigation and ground water recharge. The potential of this Region lies with only one industrial zone, Lomas and Observatorio.

The total amount of wastewater available in the Region is 3.92 meter cube per second. The wastewater available exceeds the potential for reuse in the Region, which is 0.023 meter cube per second. The remaining wastewater could be utilized in another Region.

Region IV. The Region has potential for agricultural irrigation and industrial reuse. The wastewater available here is not considered appropriate for reuse due to the high degree of influence of industrial wastes. In this case the wastewater that can be considered as available for reuse is the excedents from neighboring Regions II, and III. (See Table 3.8)

Table 3.8

Wastewater Available in Region IV

Region	Excedent (m^3/sec)
II	8.76
III	3.89
TOTAL	12.65

According to agricultural requirements, it is estimated that 4 meter cube per second could be utilized in this Region, and 3.872 in industrial reuse. (See Table 3.9). This situation would indicate a potential for reuse in this Region of 7.872 meter cube per second. An excedent wastewater of 4.778 would still remain, plus the 7.84 generated in Region IV.

Region V. The Region has potential for agricultural irrigation and industrial reuse. The total amount of wastewater available for reuse is 6.34 meter cube per second. According to agricultural requirements, it is estimated that 4.3 meter cube per second together with

Table 3.9

Industrial Zones Located in Region IV

Zone	Reuse Potential (m^3/sec)
Vallejo and Azcapotzalco	1.794
Naucalpan	0.693
Tlanepantla	0.562
Cuautitlan - Lecheria	0.700
Nicolas Romero	0.123
TOTAL	3.872

2.039 for industrial reuse (See Table 3.10) is the potential for reuse in this Region, utilizing its total wastewater availability.

Table 3.10

Industrial Zones Located in Region V

Zone	Reuse Potential (m^3/sec)
Ecatepec	1.493
Gustavo A. Madero and Tepeyac	0.546
TOTAL	2.039

The total water reuse potential in the Valley of Mexico amounts to 17.538 meter cube per second, and an excedent wastewater of 12.632, coming mainly from Regions IV, II, and III, which would still have to be drained from the Valley. The water requirements for the Valley of Mexico up to the year 2000, compared to the current supply and reuse potential are shown on Figures 3.8, 3.9, 3.10.

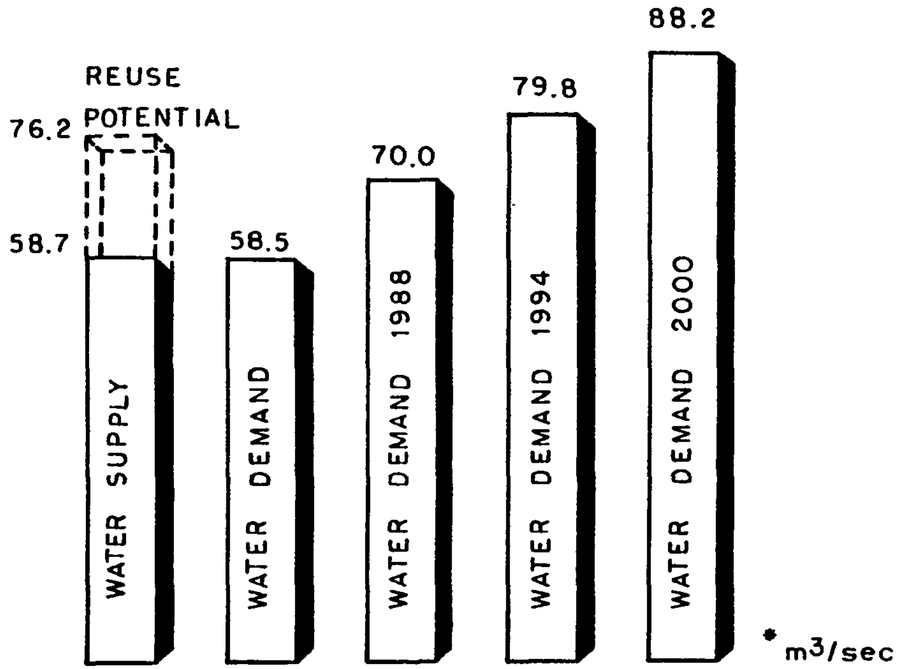


Figure 3.8. Water Requirements for the Valley of Mexico up to the Year 2000, Compared to the Current Water Supply and Reuse Potential (Alternative A).

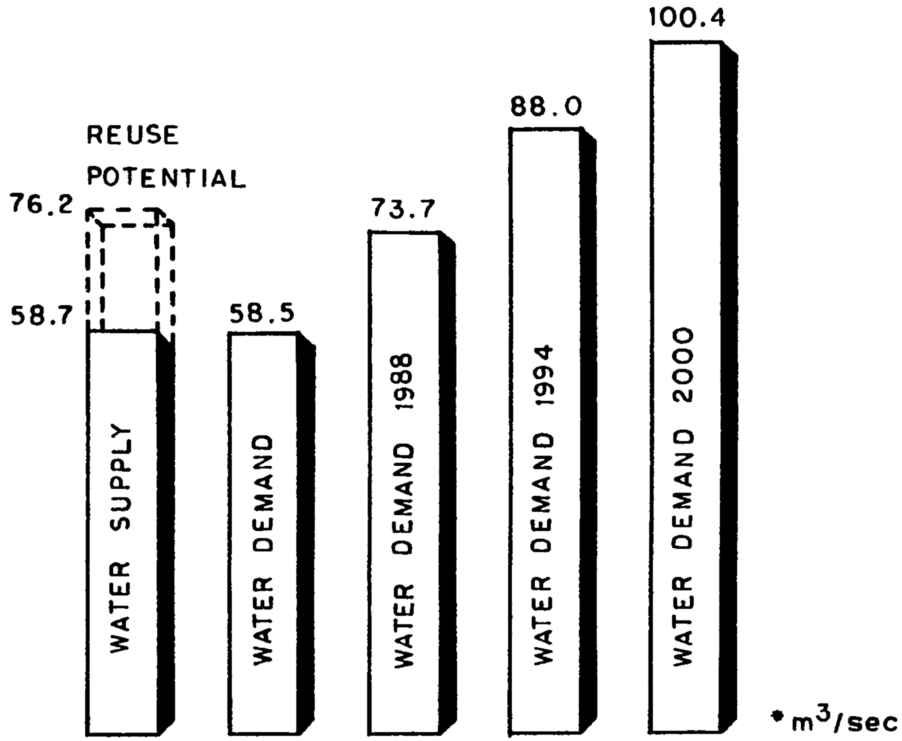


Figure 3.9. Water Requirements for the Valley of Mexico up to the Year 2000, Compared to the Current Water Supply and Reuse Potential (Alternative B).

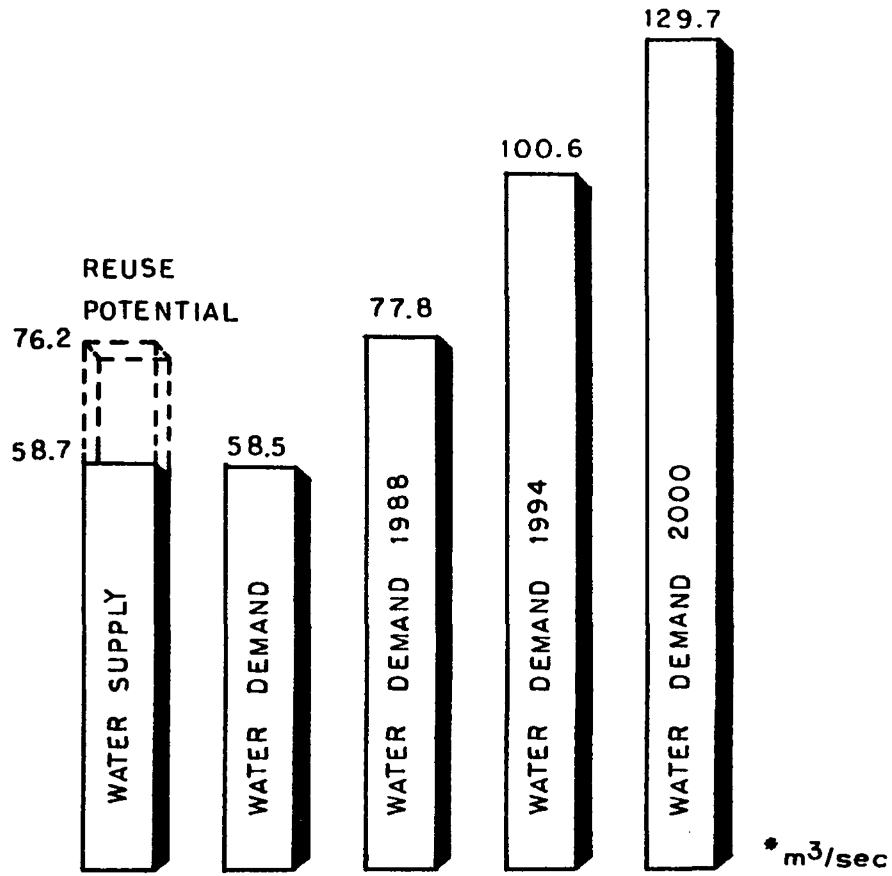


Figure 3.10. Water Requirements for the Valley of Mexico up to the Year 2000, Compared to the Current Water Supply and Reuse Potential (Alternative C).

CHAPTER IV

METHODOLOGY

Introduction

To establish a model for the selection of the best alternative choice regarding water reuse, a factor priority rating system is conducted. The technique considered as the most appropriate for the assignment of priorities in cases where the information is insufficient, unreliable, and subjective judgment is required, is the Delphi Technique. The model obtained from this study provides an empirical scheme to facilitate the decision-making process with reference to water reuse.

The Delphi Method

In the early 1950's the Delphi Method was developed by the RAND Corporation under contract with the United States Air Force[24]. The objective of this methodology is to obtain the most reliable consensus from a panel of experts, by means of a series of intensive questionnaires and controlled opinion feedback.

The conduction of the Delphi requires the following steps: selection of a coordinator who would be in charge of submitting the questionnaires, and the analysis of the responses; selection of panel and preparation of questionnaires; individual assessment of questionnaires by panel experts; pooling of results and statistical analysis;

experts' review of their own answers together with group responses by the panelists.

The main advantages of the Delphi are its low cost, and its avoidance of direct confrontation of experts with one another. The Delphi is an iterative process which gains from the knowledge of experts in order to quantify factors which would otherwise be very difficult to quantify.

In this study the Delphi is utilized to determine the weights of several factors involved in the decision-making process towards the selection of the best alternative choice regarding water reuse. The analysis was conducted with a panel of experts, where the mean of the responses was taken as the consensus.

The Delphi exercise is subjected to four phases. The first is the exploration of the subject under discussion, in this case panel members indicate what they feel is pertinent to water reuse. The second phase consists of understanding how the panel views the subject. The third phase is the exploration of any disagreement between panel members. The last phase is the final evaluation of the responses once they have been fed back to the panel.

This study deals with an empirical methodology which facilitates the complex decision-making process in the selection of the best water reuse alternative by simplifying the assessment of the factors. The coefficients for this methodology are achieved by agreement between a group of experts and are in no way supported by any theoretical considerations.

A list of highly potential respondents was developed from people who, in one way or another, had participated in water reuse symposiums; therefore, we assumed they had a high interest and expertise in the field. Invitations to participate in the Delphi exercise were sent to the potential respondents in an effort to secure a significant participation.

The first questionnaire was distributed in February and consisted of three parts: the first, general information about the panel of experts; the second, subjective assignment of level of importance to the factors mentioned in the questionnaire and the establishment of best alternative choice regarding each of the factors; the third, comments that the panelist would consider pertinent. Additional items such as a brief description of the Delphi technique and a glossary of terms were included. The results of the first questionnaire are presented in Table 3.1. The panelists were asked to check with a 1 or a 0 the pairs of factors according to their relative importance.

The responses to the first questionnaire reveal substantial agreement regarding the importance of public health aspects, water quality requirements, and public acceptance. Less agreement occurs with capital cost of the treatment system and operation and maintenance cost. No agreement is achieved regarding the importance of water exchange and legal and institutional considerations.

Analysis of Results

The weighted ranking technique was used to process the questionnaire.[25] A matrix is formed, where the expert's response represents the (j) columns and the decision factors represent the matrix rows (i). The expert by assigning a 0 or a 1 enters a weight for each specific factor, the weight is obtained by adding the ones on a matrix row and dividing the sum by the sum of all matrix rows which is the Factor Importance Coefficient (FIC). Therefore, each factor has a FIC and the sum of these equals 1. The same procedure is applied to obtain the alternative choice coefficient (ACC) with regards to each decision factor.

A final matrix is obtained by multiplying the Factor Importance Coefficient (FIC) and alternative choice coefficient (ACC). By adding the coefficients in this new matrix for each alternative, the one that shows the highest number is the best choice.

The second round questionnaire was sent to minimize any variation of opinions. This was done to show the experts the range and the average weight of each decision factor and of each alternative in order to give them a better understanding of the group response and to facilitate a reconsideration of their first reply. It was assumed that the experts who did not return the second questionnaire did not wish to make any changes to their first reply. Therefore, their response to the first questionnaire was utilized.

The results of the complete delphi exercise and the list of participating experts are shown in Table 4.1 through Table 4.12.

The comments that were made by the experts include the following: Dr. Aguirre stated that his answers reflect his own personal opinion and necessarily that of the agency he represents.

Dr. Ballance indicated that a more detailed description of the water reuse alternatives would have been very helpful, that the alternatives lacked precision and that it was necessary to make certain assumptions which may have not been correct. Dr. Bartone suggested that in many cases it is difficult to rank the factors or alternatives because of the indifference to the choices given, or because some of the choices have little practical meaning and that therefore, ties should be allowed rather than being restricted to purely dichotomous responses unless this would cause severe methodological problems. Dr. Bartone also mentioned that many of the judgments to respond to the questionnaire require a more detailed knowledge of project conditions. Dr. Bonilla indicated that his answers respond to conditions actually observed in the Valley of Mexico and do not apply to any other area. Mr. Calderon mentioned that the questionnaire served to stimulate critical thinking. Dr. Digiano found the exercise interesting and expressed some reservations with regards to decision factors such as water exchange which might have caused him not to react logically because of his not being familiar with the details. Mr. Garrison stated that some of the decision factors were not adequately explained and that, because of this all participants may not have used the same criteria. Dr. Indelecato mentioned that he considered agricultural irrigation the best water reuse alternative for municipal wastewater. Mr. McBride indicated that his answers are based on the assumption that the wastewater would receive secondary treatment, that direct reuse should not be considered regardless of cost savings, that groundwater recharge is not recommended without advanced treatment of wastewater, including nitrogen removal and that additional information is required to assess other intended alternatives. Dr. Sheikh found the questionnaire to be well designed even though he suggested that the greatest difficulty for the respondents might have been in their keeping the decision factors from interfering with one another. Mr. Smith suggested that more clarification of the terminology used in the questionnaire is necessary for it to be better understood. Mr. Teller expressed some confusion with regards to water exchange. Dr. Yang commented that further explanation of the decision factors is necessary and that the terms best and worst choice are misleading.

In the following pages examples of the technique are shown:

Step A consists of the development of factor importance coefficients (FIC) for each decision factor, in this case the respondant assigned the highest weight to public health aspects considering this to be the most important over all factors.

Step B consists of the development of the alternative choice coefficient (ACC) for each decision factor. In the example, the respondant evaluates the water reuse alternatives against public health as the decision factor. In this case the alternative that ranks as the most appropriate, is ground water recharge (surface spreading) and the second most appropriate industrial reuse.

Step C consists of the development of a final choice matrix by multiplying each (FIC) by each (ACC), and the summation of the columns. The reuse alternative that presents the highest number is the best choice water reuse alternative.

A. Development of factor importance coefficients (FIC) for each factor, depending on the individual answers to the questionnaire.

FACTORS	ASSIGNMENT OF IMPORTANCE		FIC	
Public Health Aspects	1 1 1 1 1 1 1	7	7/28	0.250
Water Quality Requirements	0 1 0 1 1 1 1	5	5/28	0.178
Water Exchange	0 0 0 0 1 0 1	2	2/28	0.071
Capital Cost of Treatment System	0 1 1 0 1 0 1	4	4/28	0.143
Operation and Maintenance Cost	0 0 1 1 1 0 1	4	4/28	0.143
Legal and Institutional Considerations	0 0 0 0 0 0 1	1	1/28	0.036
Public Acceptance	0 0 1 1 1 1 1	5	5/28	0.179
DUMMY	0 0 0 0 0 0 0	0	0/28	0.000
	$\frac{n(n-1)}{2}$ =	28		1.000

n = No. of Factors
Dummy = Least Significant Factor
1 = Most Important
0 = Least Important

B. Development of the Alternative choice coefficient (ACC) for each decision factor.

	WATER REUSE ALTERNATIVES	Public Health Aspects DECISION FACTOR			ACC
A	Aquaculture	10000011	3	3/36	0.083
B	Domestic (Potable)	0 0000001	1	1/36	0.028
C	Domestic (Non-Potable)	1 1 000011	4	4/36	0.111
D	Agricultural Irrigation	1 1 1 10011	6	6/36	0.167
E	Landscape Irrigation	1 1 1 0 0011	5	5/36	0.139
F	Industrial	1 1 1 1 1 011	7	7/36	0.194
G	Groundwater Recharge (Surface Spreading)	1 1 1 1 1 1 11	8	8/36	0.222
H	Groundwater Recharge (Direct Injection)	0 1 0 0 0 0 0 1	2	2/36	0.056
	DUMMY	0 0 0 0 0 0 0	0	0/36	0.000
		$n\frac{(n-1)}{2}$ =	36		1.000

n = No of Factors
Dummy = The Worst Choice
0 = Worst Choice
1 = Best Choice

C. Development of final choice matrix by multiplying each FIC by each ACC.

		ACC								
		Alternatives								
Factor	FIC	A	B	C	D	E	F	G	H	Sum
Public Health Aspects	0.250	0.083	0.028	0.111	0.167	0.139	0.194	0.222	0.056	1.000
Water Quality Requirements	0.178	0.111	0.056	0.111	0.167	0.194	0.194	0.111	0.056	1.000
Water Exchange	0.071	0.167	0.028	0.111	0.139	0.222	0.194	0.083	0.056	1.000
Capital Cost of Treatment System	0.143	0.111	0.028	0.083	0.222	0.167	0.194	0.139	0.056	1.000
Operation and Maintenance Cost	0.143	0.167	0.028	0.111	0.222	0.139	0.167	0.111	0.056	1.000
Legal and Institutional Considerations	0.036	0.139	0.028	0.083	0.194	0.167	0.222	0.111	0.056	1.000
Public Acceptance	0.178	0.139	0.028	0.083	0.194	0.167	0.222	0.111	0.056	1.000
Sum	1.000									

Final Choice Matrix

Factor	Alternatives							
	A	B	C	D	E	F	G	H
Public Health Aspects	0.020	0.007	0.027	0.041	0.034	0.048	0.055	0.014
Water Quality Requirements	0.019	0.010	0.019	0.029	0.034	0.034	0.019	0.010
Water Exchange	0.011	0.002	0.007	0.009	0.015	0.013	0.005	0.004
Capital Cost of Treatment System	0.015	0.004	0.011	0.031	0.023	0.027	0.019	0.008
Operation and Maintenance Cost	0.023	0.004	0.015	0.031	0.019	0.023	0.015	0.007
Legal and Institutional Considerations	0.005	0.001	0.003	0.007	0.006	0.008	0.004	0.002
Public Acceptance	0.024	0.005	0.014	0.034	0.029	0.039	0.019	0.010
	0.117	0.033	0.096	0.182+	0.160	0.160	0.136	0.055

+The Best Choice

D. Statistical analysis of the responses in order to establish the means

Table 4.1

List of Panel Members for the Delphi

No.	Name	Organization
1	Dr. Jorge Aguirre Martinez	Secretaria de Agricultura y Recursos Hidraulicos, Mexico.
2	Dr. R.C. Ballance	World Health Organization, Switzerland.
3	Dr. Carl R. Bartone	Centro Panamericano de Ingenieria Sanitaria y Ciencias del Ambiente, Peru.
4	Dr. Waldo Bonilla Dominguez	Universidad Nacional Autonoma de Mexico.
5	Mr. Jose Luis Calderon B.	Secretaria de Desarrollo Urbano y Ecologia, Mexico.
6	Mr. William J. Cooper	Florida International University, U.S.A.
7	Dr. Francis A. Digiano	University of North Carolina, U.S.A.
8	Dr. Frank M. D'itri	Institute of Water Research, U.S.A.
9	Mr. Walter E. Garrison	County Sanitation Districts of Los Angeles County, U.S.A.
10	Dr. Salvatore Idelecato	Universita Di Catania, Italy.
11	Mr. George Mc Bride	Oklahoma State Departament of Health, U.S.A.
12	Mr. Kenneth J. Miller	CH_2M-Hill, U.S.A.
13	Mr. Leon Myers	Environmental Protection Agency U.S.A.
14	Mr. M. Seager	International Reference Centre for Community Water Supply and Sanitation, the Netherlands.
15	Dr. Bahman Sheikh	Engineering - Science, U.S.A.
16	Mr. Homero Silva	Engineering Enterprices, U.S.A.

17	Mr. M.A. Smith	Departament of the Premier and Gabinet, Australia.
18	Mr. Joe P. Teller	Gulf Coast Waste Disposal Authority, U.S.A.
19	Dr. Jing-Yea Yang	Life Systems Inc. U.S.A.

Table 4.2

Distribution of Factor Importance Coefficients

Name	Decision Factor						
	Public Health	Water Quality Requirements	Water Exchange	Capital Cost of Treatment System	Operation and Maintenance Cost	Legal and Institutional Considerations	Public Acceptance
1. Dr. Jorge Aguirre	0.250	0.214	0.178	0.071	0.071	0.071	0.143
2. Dr. R.C. Ballance	0.178	0.214	0.036	0.071	0.107	0.214	0.178
3. Dr. Carl R. Bartone	0.250	0.178	0.036	0.107	0.143	0.143	0.143
4. Dr. Waldo Bonilla	0.036	0.143	0.178	0.107	0.071	0.250	0.214
5. Mr. Jose Luis Calderon	0.107	0.071	0.178	0.178	0.214	0.107	0.143
6. Dr. William J. Cooper	-	-	-	-	-	-	-
7. Dr. Francis A. Digiano	0.178	0.178	0.107	0.036	0.107	0.143	0.250
8. Dr. Frank M. D'itri	0.214	0.175	0.104	0.113	0.114	0.107	0.175
9. Mr. Walter E. Garrison	0.250	0.178	0.071	0.143	0.143	0.036	0.179
10. Dr. Salvatore Indelecato	0.250	0.178	0.143	0.036	0.214	0.107	0.071
11. Mr. George Mc Bride	-	-	-	-	-	-	-
12. Mr. Kenneth J. Miller	0.250	0.143	0.107	0.071	0.071	0.214	0.143
13. Mr. Leon Myers	0.250	0.178	0.036	0.143	0.178	0.071	0.143
14. Mr. M. Seager	0.250	0.214	0.036	0.107	0.143	0.071	0.178
15. Dr. Bahman Sheikh	0.250	0.178	0.214	0.036	0.071	0.107	0.143
16. Mr. Homero Silva	0.250	0.071	0.107	0.143	0.178	0.036	0.214
17. Mr. M.A. Smith	0.250	0.107	0.107	0.214	0.107	0.036	0.178
18. Mr. Joe P. Teller	-	-	-	-	-	-	-
19. Dr. Jing-Yea Yang.	0.214	0.250	0.143	0.107	0.071	0.036	0.178
Average	0.214	0.167	0.111	0.105	0.125	0.109	0.167

Table 4.3

Distribution of Alternative Choice Coefficients
According to Public Health as the Decision Factor.

Name	Water Reuse Alternatives							
	Aquaculture	Domestic (Potable)	Domestic (Non-Potable)	Agricultural Irrigation	Landscape Irrigation	Industrial	Groundwater Recharge (Surface Spreading)	Groundwater Recharge (Direct Injection)
1. Dr. Jorge Aguirre	0.056	0.028	0.194	0.167	0.139	0.222	0.111	0.083
2. Dr. R.C. Ballance	0.139	0.028	0.056	0.111	0.194	0.222	0.167	0.083
3. Dr. Carl R. Bartone	0.056	0.028	0.111	0.083	0.222	0.194	0.139	0.167
4. Dr. Waldo Bonilla	0.083	0.028	0.056	0.194	0.167	0.222	0.111	0.139
5. Mr. Jose Luis Calderon	0.056	0.028	0.111	0.167	0.167	0.194	0.194	0.083
6. Dr. William J. Cooper	0.139	0.028	0.083	0.083	0.167	0.222	0.111	0.167
7. Dr. Francis A. Digiano	0.056	0.028	0.139	0.139	0.194	0.222	0.139	0.083
8. Dr. Frank M. D'itri	0.125	0.030	0.109	0.134	0.174	0.194	0.137	0.100
9. Mr. Walter E. Garrison	0.083	0.028	0.111	0.167	0.139	0.194	0.222	0.056
10. Dr. Salvatore Indelecato	0.111	0.028	0.056	0.222	0.194	0.167	0.083	0.139
11. Mr. George Mc Bride	0.139	0.028	0.167	0.222	0.111	0.194	0.083	0.056
12. Mr. Kenneth J. Miller	0.139	0.028	0.167	0.111	0.194	0.222	0.083	0.056
13. Mr. Leon Myers	0.167	0.028	0.111	0.083	0.222	0.167	0.167	0.056
14. Mr. M. Seager	0.167	0.028	0.083	0.083	0.194	0.222	0.139	0.083
15. Dr. Bahman Sheikh	0.167	0.028	0.056	0.222	0.194	0.139	0.111	0.083
16. Mr. Homero Silva	0.056	0.028	0.083	0.111	0.167	0.222	0.139	0.194
17. Mr. M.A. Smith	0.111	0.028	0.056	0.083	0.139	0.167	0.222	0.194
18. Mr. Joe P. Teller	0.039	0.028	0.083	0.111	0.167	0.222	0.194	0.056
19. Dr. Jing-Yea Yang	-	-	-	-	-	-	-	-
Average	0.111	0.028	0.102	0.139	0.175	0.200	0.142	0.104

Table 4.4

Distribution of Alternative Choice Coefficients According to the Water Quality Requirements as the Decision Factor.

Name	Water Reuse Alternatives							
	Aquaculture	Domestic (Potable)	Domestic (Non-Potable)	Agricultural Irrigation	Landscape Irrigation	Industrial	Groundwater Recharge (Surface Spreading)	Groundwater Recharge (Direct Injection)
1. Dr. Jorge Aguirre	0.111	0.028	0.222	0.194	0.167	0.139	0.083	0.056
2. Dr. R.C. Ballance	0.167	0.028	0.056	0.139	0.222	0.139	0.167	0.083
3. Dr. Carl R. Bartone	0.083	0.028	0.111	0.111	0.167	0.083	0.194	0.222
4. Dr. Waldo Bonilla	0.083	0.028	0.056	0.194	0.167	0.222	0.111	0.139
5. Mr. Jose Luis Calderon	0.111	0.028	0.083	0.222	0.194	0.139	0.167	0.056
6. Dr. William J. Cooper	0.111	0.028	0.139	0.167	0.083	0.167	0.111	0.194
7. Dr. Francis A. Digiano	0.083	0.028	0.139	0.083	0.139	0.222	0.167	0.139
8. Dr. Frank M. D'itri	0.148	0.030	0.109	0.144	0.181	0.148	0.141	0.100
9. Mr. Walter E. Garrison	0.111	0.056	0.111	0.167	0.194	0.194	0.111	0.056
10. Dr. Salvatore Indelecato	0.083	0.028	0.056	0.222	0.194	0.139	0.167	0.111
11. Mr. George Mc Bride	0.194	0.028	0.111	0.222	0.167	0.139	0.083	0.056
12. Mr. Kenneth J. Miller	0.194	0.028	0.139	0.111	0.222	0.111	0.139	0.056
13. Mr. Leon Myers	0.194	0.028	0.111	0.111	0.222	0.111	0.167	0.056
14. Mr. M. Seager	0.222	0.028	0.056	0.083	0.139	0.194	0.139	0.139
15. Dr. Bahman Sheikh	0.167	0.028	0.111	0.194	0.222	0.056	0.139	0.083
16. Mr. Homero Silva	0.111	0.028	0.056	0.139	0.194	0.167	0.222	0.083
17. Mr. M.A. Smith	0.111	0.028	0.056	0.083	0.139	0.222	0.194	0.167
18. Mr. Joe P. Teller	0.167	0.028	0.083	0.139	0.167	0.167	0.167	0.083
19. Dr. Jing-Yea Yang	-	-	-	-	-	-	-	-
Average	0.136	0.030	0.100	0.157	0.177	0.153	0.148	0.104

Table 4.5

Distribution of Alternative Choice Coefficients According to the Water Exchange as the Decision Factor.

Name	Aquaculture	Domestic (Potable)	Domestic (Non-Potable)	Agricultural Irrigation	Landscape Irrigation	Industrial	Groundwater Recharge (Surface Spreading)	Groundwater Recharge (Direct Injection)
	Water Reuse Alternatives							
1. Dr. Jorge Aguirre	0.111	0.028	0.194	0.139	0.167	0.222	0.083	0.056
2. Dr. R.C. Ballance	0.167	0.028	0.056	0.111	0.222	0.194	0.139	0.083
3. Dr. Carl R. Bartone	0.083	0.028	0.056	0.194	0.167	0.222	0.111	0.139
4. Dr. Waldo Bonilla	0.083	0.028	0.056	0.194	0.167	0.222	0.111	0.139
5. Mr. Jose Luis Calderon	0.111	0.028	0.111	0.222	0.139	0.194	0.111	0.083
6. Dr. William J. Cooper	-	-	-	-	-	-	-	-
7. Dr. Francis A. Digiano	-	-	-	-	-	-	-	-
8. Dr. Frank M. D'itri	0.142	0.030	0.086	0.158	0.181	0.161	0.139	0.103
9. Mr. Walter E. Garrison	0.167	0.028	0.111	0.139	0.222	0.194	0.083	0.056
10. Dr. Salvatore Indelecato	0.111	0.028	0.056	0.222	0.194	0.139	0.139	0.111
11. Mr. George Mc Bride	0.194	0.028	0.111	0.222	0.167	0.139	0.083	0.056
12. Mr. Kenneth J. Miller	0.167	0.028	0.194	0.139	0.222	0.056	0.111	0.083
13. Mr. Leon Myers	0.111	0.028	0.083	0.139	0.222	0.194	0.167	0.056
14. Mr. M. Seager	0.222	0.028	0.083	0.111	0.167	0.194	0.111	0.083
15. Dr. Bahman Sheikh	0.083	0.028	0.056	0.222	0.139	0.111	0.194	0.167
16. Mr. Homero Silva	0.111	0.028	0.056	0.194	0.111	0.222	0.139	0.111
17. Mr. M.A. Smith	0.222	0.028	0.083	0.194	0.111	0.139	0.167	0.056
18. Mr. Joe P. Teller	0.139	0.028	0.083	0.111	0.139	0.194	0.222	0.083
19. Dr. Jing-Yea Yang	-	-	-	-	-	-	-	-
Average	0.139	0.028	0.092	0.169	0.171	0.175	0.132	0.092

Table 4.6

Distribution of Alternative Choice Coefficients According to the Capital Cost of the Treatment System as the Decision Factor.

Name	Water Reuse Alternatives							
	Aquaculture	Domestic (Potable)	Domestic (Non-Potable)	Agricultural Irrigation	Landscape Irrigation	Industrial	Groundwater Recharge (Surface Spreading)	Groundwater Recharge (Direct Injection)
1. Dr. Jorge Aguirre	0.056	0.028	0.222	0.194	0.167	0.111	0.139	0.083
2. Dr. R.C. Ballance	0.222	0.028	0.056	0.167	0.194	0.111	0.139	0.083
3. Dr. Carl R. Bartone	0.111	0.028	0.111	0.139	0.222	0.056	0.167	0.167
4. Dr. Waldo Bonilla	0.083	0.028	0.056	0.167	0.194	0.222	0.111	0.139
5. Mr. Jose Luis Calderon	0.111	0.028	0.083	0.222	0.194	0.139	0.167	0.056
6. Dr. William J. Cooper	0.139	0.028	0.083	0.222	0.167	0.083	0.194	0.083
7. Dr. Francis A. Digiano	0.111	0.028	0.083	0.139	0.167	0.222	0.194	0.056
8. Dr. Frank M. D'itri	0.153	0.030	0.086	0.178	0.176	0.137	0.150	0.090
9. Mr. Walter E. Garrison	0.111	0.028	0.083	0.222	0.167	0.194	0.139	0.056
10. Dr. Salvatore Indelecato	0.111	0.028	0.056	0.222	0.194	0.083	0.167	0.139
11. Mr. George Mc Bride	0.222	0.028	0.139	0.194	0.111	0.167	0.083	0.056
12. Mr. Kenneth J. Miller	0.167	0.028	0.083	0.222	0.194	0.111	0.139	0.056
13. Mr. Leon Myers	0.139	0.028	0.083	0.167	0.222	0.111	0.194	0.056
14. Mr. M. Seager	0.194	0.028	0.056	0.139	0.222	0.083	0.167	0.111
15. Dr. Bahman Sheikh	0.167	0.028	0.139	0.222	0.167	0.056	0.139	0.083
16. Mr. Homero Silva	0.139	0.028	0.056	0.193	0.167	0.167	0.167	0.083
17. Mr. M.A. Smith	0.083	0.028	0.056	0.111	0.222	0.139	0.194	0.167
18. Mr. Joe P. Teller	0.222	0.028	0.056	0.083	0.194	0.139	0.167	0.111
19. Dr. Jing-Yea Yang	-	-	-	-	-	-	-	-
Average	0.141	0.028	0.089	0.178	0.186	0.130	0.157	0.093

Table 4.7

Distribution of Alternative Choice Coefficients According to the Operation and Maintenance Cost of a Treatment System as the Decision Factor

Name	Water Reuse Alternatives							
	Aquaculture	Domestic (Potable)	Domestic (Non-Potable)	Agricultural Irrigation	Landscape Irrigation	Industrial	Groundwater Recharge (Surface Spreading)	Groundwater Recharge (Direct Injection)
1. Dr. Jorge Aguirre	0.083	0.028	0.222	0.194	0.139	0.111	0.167	0.056
2. Dr. R.C. Ballance	0.222	0.028	0.056	0.167	0.194	0.111	0.139	0.083
3. Dr. Carl R. Bartone	0.111	0.056	0.111	0.139	0.167	0.083	0.194	0.139
4. Dr. Waldo Bonilla	0.083	0.028	0.056	0.194	0.167	0.222	0.139	0.111
5. Mr. Jose Luis Calderon	0.111	0.028	0.083	0.222	0.194	0.139	0.167	0.056
6. Dr. William J. Cooper	0.194	0.028	0.139	0.139	0.222	0.083	0.139	0.056
7. Dr. Francis A. Digiano	0.222	0.028	0.083	0.111	0.139	0.194	0.167	0.056
8. Dr. Frank M. D'itri	0.160	0.030	0.100	0.176	0.176	0.134	0.137	0.084
9. Mr. Walter E. Garrison	0.167	0.028	0.111	0.222	0.139	0.167	0.111	0.056
10. Dr. Salvatore Indelecato	0.111	0.028	0.056	0.222	0.194	0.083	0.167	0.139
11. Mr. George Mc Bride	0.167	0.028	0.167	0.167	0.111	0.222	0.083	0.056
12. Mr. Kenneth J. Miller	0.139	0.028	0.111	0.222	0.194	0.083	0.167	0.056
13. Mr. Leon Myers	0.167	0.028	0.083	0.194	0.222	0.111	0.139	0.056
14. Mr. M. Seager	0.222	0.083	0.056	0.111	0.167	0.194	0.083	0.083
15. Dr. Bahman Sheikh	0.167	0.028	0.111	0.222	0.139	0.056	0.167	0.111
16. Mr. Homero Silva	0.139	0.028	0.056	0.194	0.167	0.167	0.167	0.083
17. Mr. M.A. Smith	0.083	0.028	0.056	0.111	0.222	0.139	0.167	0.194
18. Mr. Joe P. Teller	0.167	0.028	0.083	0.167	0.222	0.139	0.139	0.056
19. Dr. Jing-Yea Yang	-	-	-	-	-	-	-	-
Average	0.151	0.033	0.097	0.176	0.176	0.135	0.147	0.085

Table 4.8

Distribution of Alternative Choice Coefficients According to Legal and Institutional Considerations as the Decision Factor

Name	Water Reuse Alternatives							
	Aquaculture	Domestic (Potable)	Domestic (Non-Potable)	Agricultural Irrigation	Landscape Irrigation	Industrial	Groundwater Recharge (Surface Spreading)	Groundwater Recharge (Direct Injection)
1. Dr. Jorge Aguirre	0.056	0.028	0.167	0.167	0.139	0.222	0.139	0.083
2. Dr. R.C. Ballance	0.167	0.028	0.056	0.139	0.194	0.222	0.111	0.083
3. Dr. Carl R. Bartone	0.139	0.028	0.056	0.167	0.194	0.222	0.083	0.111
4. Dr. Waldo Bonilla	0.083	0.028	0.056	0.194	0.222	0.167	0.139	0.111
5. Mr. Jose Luis Calderon	0.139	0.028	0.083	0.222	0.167	0.194	0.111	0.056
6. Dr. William J. Cooper	0.167	0.028	0.111	0.111	0.167	0.222	0.139	0.056
7. Dr. Francis A. Digiano	0.111	0.028	0.083	0.167	0.167	0.222	0.167	0.056
8. Dr. Frank M. D'itri	0.169	0.037	0.097	0.144	0.180	0.178	0.120	0.077
9. Mr. Walter E. Garrison	0.139	0.028	0.083	0.194	0.167	0.222	0.111	0.056
10. Dr. Salvatore Indelecato	0.139	0.028	0.056	0.167	0.194	0.222	0.083	0.111
11. Mr. George Mc Bride	0.222	0.139	0.167	0.111	0.083	0.194	0.056	0.028
12. Mr. Kenneth J. Miller	0.222	0.028	0.167	0.111	0.194	0.111	0.111	0.056
13. Mr. Leon Myers	0.222	0.028	0.167	0.139	0.194	0.083	0.111	0.056
14. Mr. M. Seager	0.167	0.028	0.083	0.056	0.167	0.194	0.139	0.167
15. Dr. Bahman Sheikh	0.139	0.028	0.056	0.167	0.194	0.222	0.086	0.111
16. Mr. Homero Silva	0.111	0.028	0.056	0.167	0.194	0.222	0.139	0.083
17. Mr. M.A. Smith	0.083	0.028	0.056	0.111	0.139	0.167	0.194	0.222
18. Mr. Joe P. Teller	0.222	0.028	0.083	0.139	0.194	0.167	0.111	0.056
19. Dr. Jing-Yea Yang	-	-	-	-	-	-	-	-
Average	0.150	0.035	0.094	0.149	0.175	0.192	0.119	0.088

Table 4.9

Distribution of Alternative Choice Coefficients According to Public Acceptance as the Decision Factor.

Name	Water Reuse Alternatives							
	Aquaculture	Domestic (Potable)	Domestic (Non-Potable)	Agricultural Irrigation	Landscape Irrigation	Industrial	Groundwater Recharge (Surface Spreading)	Groundwater Recharge (Direct Injection)
1. Dr. Jorge Aguirre	0.083	0.028	0.139	0.139	0.139	0.222	0.139	0.111
2. Dr. R.C. Ballance	0.194	0.028	0.056	0.083	0.139	0.222	0.167	0.111
3. Dr. Carl R. Bartone	0.139	0.028	0.056	0.167	0.194	0.222	0.111	0.083
4. Dr. Waldo Bonilla	0.083	0.028	0.056	0.111	0.167	0.222	0.139	0.194
5. Mr. Jose Luis Calderon	0.139	0.028	0.083	0.194	0.194	0.167	0.139	0.056
6. Dr. William J. Cooper	0.167	0.028	0.056	0.139	0.139	0.222	0.139	0.111
7. Dr. Francis A. Digiano	0.139	0.028	0.083	0.111	0.194	0.222	0.167	0.056
8. Dr. Frank M. D'itri	0.150	0.030	0.074	0.178	0.199	0.134	0.123	0.109
9. Mr. Walter E. Garrison	0.139	0.028	0.083	0.194	0.167	0.222	0.111	0.056
10. Dr. Salvatore Indelecato	0.083	0.028	0.056	0.111	0.139	0.222	0.167	0.194
11. Mr. George Mc Bride	0.167	0.028	0.111	0.194	0.139	0.222	0.083	0.056
12. Mr. Kenneth J. Miller	0.083	0.028	0.056	0.167	0.222	0.194	0.111	0.139
13. Mr. Leon Myers	0.222	0.028	0.056	0.111	0.194	0.139	0.167	0.083
14. Mr. M. Seager	0.194	0.028	0.056	0.083	0.167	0.222	0.139	0.111
15. Dr. Bahman Sheikh	0.139	0.028	0.056	0.139	0.167	0.222	0.083	0.167
16. Mr. Homero Silva	0.111	0.028	0.056	0.167	0.194	0.222	0.139	0.083
17. Mr. M.A. Smith	0.111	0.028	0.056	0.083	0.139	0.222	0.194	0.167
18. Mr. Joe P. Teller	0.167	0.028	0.083	0.139	0.222	0.194	0.111	0.056
19. Dr. Jing-Yea Yang	-	-	-	-	-	-	-	-
Average	0.139	0.028	0.071	0.139	0.173	0.206	0.135	0.108

Table 4.10

Average Weight Distribution of the Decision Factors Based on The Level of Education of Experts

Level of Education	Number of Experts	Decision Factor: Public Health Aspects	Water Quality Requirements	Water Exchange	Capital Cost of Treatment System	Operation and Maintenance Cost	Legal and Institutional Considerations	Public Acceptance
Bachelor	3	0.250	0.161	0.089	0.107	0.107	0.125	0.161
Master	7	0.221	0.128	0.093	0.157	0.167	0.064	0.171
Doctor	9	0.202	0.190	0.127	0.076	0.108	0.131	0.166

Table 4.11

Average Weight Distribution of the Decision Factors Based on the Place of Residence of Experts

Place of Residence	Number of Experts	Decision Factor: Public Health Aspects	Water Quality Requirements	Water Exchange	Capital Cost of Treatment System	Operation and Maintenance Cost	Legal and Institutional Considerations	Public Acceptance
Australia	1	0.250	0.107	0.107	0.214	0.107	0.036	0.178
Europe	3	0.226	0.202	0.072	0.071	0.155	0.131	0.142
Mexico	3	0.131	0.143	0.178	0.119	0.119	0.143	0.167
South America	1	0.250	0.178	0.036	0.107	0.143	0.143	0.143
United States	11	0.232	0.169	0.111	0.099	0.117	0.094	0.178

Table 4.12

Average Weight Distribution of the Decision Factors Based on the Place of Employment of Experts

Place of Employment	Number of Experts	Decision Factors: Public Health Aspects	Water Quality Requirements	Water Exchange	Capital Cost of Treatment System	Operation and Maintenance Cost	Legal and Institutional Considerations	Public Acceptance
Education	5	0.170	0.169	0.133	0.073	0.127	0.152	0.178
Government	8	0.220	0.166	0.119	0.143	0.131	0.060	0.161
Industry	3	0.250	0.131	0.143	0.083	0.107	0.119	0.167
International Organization	3	0.226	0.202	0.036	0.095	0.131	0.143	0.166

The most important decision factor to be taken into account when establishing a water reuse program is public health. The average weight of this factor, assigned by the panel of experts, was 21.4 percent. The next most important two decision factors, in terms of their weights, are water quality requirements and public acceptance, both with an average weight of 16.7 percent. The operation and maintenance cost of a treatment system follows with an average weight of 12.5 percent. Water exchanges as a decision factor has been assigned an average weight of 11.1 percent. Legal and institutional considerations have an average weight of 10.9 percent and the capital cost of the treatment system ranks last with an average weight of 10.5 percent. Based on the weights mentioned above, it is clear that the first three factors are the determining factors for any water reuse program.

The Regions of the world queried in this study have differing views on the assignment of importance to decision factors. In the case of Mexico, the importance of public health aspects, water exchange, and legal and institutional considerations differ significantly from the world averages. For the Valley of Mexico the possibility of water exchanges is considered the most important decision factor with an average weight of 17.8 percent according to experts with residence in Mexico. The second most important factors are water quality requirements and legal and institutional considerations with an average weight of 14.3 percent. Public health aspects were given a weight of only 13.1 percent.

Considering public health as the decision factor for the implementation of a water reuse program, the best alternative is industrial reuse with an average weight of 20 percent. The second best alternative is landscape irrigation with 17.5 percent. The third is groundwater recharge (surface spreading) with 14.2 percent; the fourth is agricultural irrigation with 13.9 percent; the fifth is aquaculture with 11.1 percent; the sixth is groundwater recharge (direct injection) with 10.4 percent; the seventh is domestic (non-potable) reuse with 10.2 percent; and the last is domestic (potable) with 2.8 percent.

Considering water quality requirements as the decision factor for the implementation of a water reuse program, the best reuse alternative is landscape irrigation with an average weight of 17.7 percent. The second is agricultural irrigation with 15.7 percent; the third is industrial reuse with 15.3 percent; the fourth is groundwater recharge (surface spreading) with 14.8 percent; the fifth is aquaculture with 13.6 percent; the sixth is groundwater recharge (direct injection) with 10.4 percent; the seventh is domestic (non-potable) reuse with 10.0 percent; and the eighth is domestic (potable) with 3.0 percent. From the percentage stated above, no clear distinction can be drawn between the second, third, or fourth alternatives because of the very small differences in their average weights. Therefore, these alternatives should be judged equally feasible when considering water quality requirements as the decision factor.

Considering the possibility of water exchange as the decision factor for the implementation of a water reuse program, the best alternative is industrial reuse with an average weight of 17.5 percent. The second is landscape irrigation with 17.1 percent; the third is agricultural irrigation with 16.9 percent; the fourth is aquaculture with 13.9 percent; the fifth is groundwater recharge (surface spreading) with 13.2 percent. The sixth and seventh alternative tied with 9.2 percent are groundwater recharge (direct injection) and domestic (non-potable) reuse. The last alternative is domestic (potable) reuse with 2.8 percent. From the percentages stated above no clear distinction can be drawn between the first three alternatives because of the very small difference in their average weights. Therefore, these first three water reuse alternatives should be judged equally feasible when considering water exchange as the decision factor.

Considering the capital cost of the treatment system as the decision factor for the implementation of a water reuse program, the best reuse alternative is landscape irrigation with an average weight of 18.6 percent. The second is agricultural irrigation with 17.8 percent; the third is groundwater recharge (surface spreading) with 15.7 percent; the fourth is aquaculture with 14.1 percent; the fifth is industrial reuse with 13.0 percent; the sixth is groundwater recharge (direct injection) with 9.3 percent; the seventh is domestic (non-potable) reuse with 8.8 percent; and the last is domestic (potable) reuse with 2.8 percent. The figures stated above show that clear distinctions can be made concerning the feasibility of the various alternatives when considering capital cost of the treatment system as the decision factor.

Considering the operation and maintenance cost of a treatment system as the decision factor for the implementation of a water reuse program, the best reuse alternatives are agriculture and landscape irrigation with average weights of 17.6 percent. The third alternative is aquaculture with 15.1 percent; the fourth is groundwater recharge (surface spreading) with 14.7 percent; the fifth is industrial reuse with 13.5 percent; the sixth is domestic (nonpotable) reuse with 9.7 percent; the seventh is groundwater recharge (direct injection) with 8.5 percent; and the eighth is domestic (potable) reuse with 3.3 percent.

Considering the legal and institutional considerations as the decision factor for the implementation of a water reuse program, the best reuse alternative is industrial reuse with an average weight of 19.2 percent. The second is landscape irrigation with 17.5 percent; the third is aquaculture with 15.0 percent; the fourth is agricultural irrigation with 14.9 percent; the fifth is groundwater recharge (surface spreading) with 11.9 percent; the sixth is domestic (nonpotable) reuse with 9.4 percent; the seventh is groundwater recharge (direct injection) with 8.8 percent; and the last is domestic (potable) reuse with 3.5 percent. Once again, the figures show clear distinctions can be made as to the feasibility of the various alternatives when legal and institutional considerations are the decision factor.

Considering public acceptance as the decision factor for the implementation of a water reuse program, the best reuse alternative is industrial reuse with an average weight of 20.6 percent. The second is landscape irrigation with 17.3 percent; the third and fourth alternatives are agriculture irrigation and aquaculture each with a weight of 13.9 percent. The fifth is groundwater recharge (surface spreading) with 13.5 percent; the sixth is groundwater recharge (direct injection) with 10.8 percent; the seventh is domestic (non-potable) reuse with 7.1 percent; and the last is domestic (potable) with 2.8 percent.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Introduction

The Valley of Mexico, as well as many other regions in the world, is experiencing acute water shortages mainly due to population explosion , industrial development, and limited water resources. This situation has led planners to consider water reuse as a viable alternative for increasing water availability. The empirical methodology developed in this study will provide guidelines to planners involved with water reuse in the Valley of Mexico, as well as other regions in the world, by giving them the judgment tools and priorities to analyze and select the best reuse alternative for each specific case.

Summary

Chapter I defines the problem, which is the inability of the water supply to meet the demand. This problem has resulted from the high cost of importing water from neighboring basins to the Valley of Mexico and the rapid growth of the industrial and municipal demand. The objectives of this dissertation are to develop an empirical methodology which would aid the decision-makers and planners in the selection of a best choice water reuse alternative and to present water reuse as a viable possibility for increasing water availability in the Valley by indicating the uses and volumes that could be reclaimed.

Chapter II describes the most widely spread applications of reclaimed water, placing special emphasis on industrial reuse, agricultural reuse, and ground water recharge. It illustrates the sources of wastewater in the Valley of Mexico as well as the current reuse practices in Mexico and the United States. In addition, some selected parameters and their required concentration for each specific reuse alternative are presented.

Chapter III analyzes and identifies the major water uses that present the possibility of utilizing reclaimed water. The regionalization of the Valley is conducted to facilitate the analysis and allocation of the reclaimed water as well as the determination of the amounts of wastewater available for reuse. The sewer lines are considered as the potential source of wastewater. A comparative analysis of the water quality requirements and the wastewater quality is also illustrated.

Chapter IV describes the Delphi technique which is utilized to determine the weights of the major decision factors involved in the selection of the best water reuse alternative. The Delphi is also utilized to indicate the best and worst choice alternative with respect to each of the decision factors. The analyses of the responses to the questionnaires sent to technical experts are presented to determine the relative importance weights of public health, water quality requirements, water exchange, capital cost of treatment system, operation and maintenance cost, legal and institutional considerations, and public acceptance.

In order to aid in the development of the conclusions a brief summary of the findings is presented:

Based on the projections of this study, the water demand for the Valley of Mexico is expected to increase from 58.5 meter cube per second in the year 1982 to 88.2 in the year 2000, according to growth Alternative A.

Based on the projections of this study, the water demand for the Valley of Mexico is expected to increase from 58.5 meter cube per second in the year 1982 to 100.4 in the year 2000, according to growth Alternative B.

Based on the projections of this study, the water demand for the Valley of Mexico is expected to increase from 58.5 meter cube per second in the year 1982 to 129.7 in the year 2000, according to growth Alternative C.

In general, the quality of the wastewater generated in the Valley can be considered suitable for reuse after being subjected to primary and secondary treatment. The required degree of treatment will depend on the quality and intended use of the wastewater.

Based on the projections of this study, the current total water reuse potential for the Valley of Mexico amounts to 17.5 meter cube per second. This represents 29.9 percent of the current water demand.

The Valleys' agricultural and industrial water demand is expected to increase only slightly in the years preceding the year 2000. However, municipal water demand is expected to increase significantly in the next two decades.

Regions I and IV have a tremendous potential for industrial water reuse. Regions I and V have great potential for agriculture reuse and Region I is expected to be adequate for large scale groundwater recharge.

Conclusions

Based on the findings of this study a number of conclusions concerning both the viability of water reuse and the applicability of the methodology utilized can be drawn.

1. Although water reuse has been proven to be a feasible option for alleviating part of the excessive water demand in the Valley of Mexico, it is not a cure all. Total utilization of reuseable water would only meet 59% of the estimated increase in the demand by the year 2000, for the most conservative case. It becomes obvious that other sources of water will have to be developed to meet projected increases in demand.

2. Three techniques may be utilized to conduct a cost comparison study; cost effectiveness analysis, cost benefit analysis, and minimum cost analysis. In the case of the Valley of Mexico these techniques cannot be applied because of unavailability of data and the nonquantifiable characteristics of some decision factors. Nevertheless, based on studies from the United States the cost of water reuse, in general, is less than the cost of transferring water from other basins at great distances. In some cases the cost can be ten to twenty five times higher, due mainly to the transportation and reservoir development costs.

3. The urgency of implementing a comprehensive water reuse program can not be overstated. The alarming rates of growth in water demand coupled with the limited and costly current sources of fresh water indicate an immediate need for a water reuse program which could help alleviate water shortages.

4. The methodology used in this study can be adapted to meet specific needs of communities with unique conditions. At the same time the deletion of decision factors can decrease the reliability of the best choice alternative.

5. There are three major problems associated with this study. The first problem is that the decision factors are not completely independent of one another, making it difficult for the panel of experts to assign important ratings based on similar considerations. In other words, the general nature of the decision factors can cause the experts to have widely differing interpretations of these factors. The second problem is that although the questionnaire was designed to reduce any misunderstanding between the expert and the researcher, some difficulty with the terminology utilized arose because of language differences. Such was the case with the possibility of water exchange. The third problem stems from the fact that little information is available regarding water distribution and water quality in the Valley of Mexico.

6. The responses to the Delphi questionnaire may indicate a tendency by the respondents to assign a higher weight to a decision factor when the factor is closely related to their professional practice. It should be pointed out that in this study the

backgrounds of the respondents lie mainly in engineering and science, there exists a void in other fields that should receive attention in future studies. A more equitable distribution of expertise including representatives from the legal, economic, medical, and public interest groups would be desirable.

Recommendations

Based on the results of this study, a number of recommendations can be developed. These recommendations are outlined below:

1. Currently, available and future data should be centralized at a national hydrological information center. The data at this center should be made readily accessible to qualified personnel. The creation of this data center should be a high priority objective.

2. The resources required for development of a comprehensive water reuse program should be allocated and scheduled in accordance to the rankings developed by the panel of experts. For example, first priority should be given to industrial reuse. The other alternatives should then be considered in order.

3. One means of increasing current water availability in the Valley of Mexico would be construction of surface impoundments. Reservoirs could be developed at several sites surrounding the Valley. This alternative is low cost compared to transferring water from other basins and should be fully studied and evaluated, for economic, technical and environmental feasibility.

4. The existing and future development of the Deep Drainage

Program, the desiccation of Texcoco Lake, the over exploitation of the underlying fresh water aquifer, and the explosive urban growth have seriously disrupted the natural ecosystem of the Valley of Mexico. One remedial measure which should be implemented immediately is groundwater recharge through surface spreading. This study has shown this to be one of the most attractive reuse alternatives for the Valley.

5. As an initial step in the development of a comprehensive water reuse program, each region should initiate studies to rank the decision factors applicable to that region and based on those factors, rank the water reuse alternatives.

6. Appropriate legislation should be implemented to allow water reuse when it is shown to be technically, economically, and environmentally feasible. At the same time, criteria or standards of minimum water quality requirements for the different water reuse alternatives should be developed.

7. Water exchanges should be encouraged by government agencies by providing economic incentives to users of reclaimed water.

8. In the judgement of the author a comprehensive water resources management program for the Valley of Mexico should include:

I. A more rational use of existing water supplied in the Valley of Mexico by means of the following specific actions:

   a. Education programs directed towards developing a public awareness of the need for water conservation.
   b. Implementation of realistic water prices.
   c. Metering water use.

d. Mandated water rationing when needed.
e. Reduction in water losses by upgrading existing water distribution systems.

II. Increasing water supplies in the Valley of Mexico by:

a. Water reuse through industrial reuse, groundwater recharge (surface spreading), landscape irrigation, and agricultural irrigation in that order.
b. Development of feasible surface water impoundment sites.
c. Inter-basin water transfers at the current level with little emphasis towards future expansion.

9. Further study is required with regards to the selection of the water reuse decision factors. The selection and ranking of the decision factors could have been conducted by means of a double Delphi. In such cases, the experts might be prejudiced by their previous choice of the decision factors. For this study the factors were obtained from research conducted in different parts of the world. Even though there are decision factors that seem to overlap, they consist of elements that are mutually exclusive.

10. Further study with regards to cost comparison analysis is required. References for this study include; "U.S. Senate Select Committee", Print 27, 1969; "The Manual of Standarized Procedures for Estimating Cost of Conventional Water Supplies", Black and Veatch,, 1963; and the "Construction Costs for Wastewater Treatment Plants", EPA, 1980. The reuse cost is only that of treatment varying with use, the fresh water use includes impoundment, transport, and treatment. The issue really is one of the willingness to use reuse water for various uses, issue which the Delphi addresses. Water reuse becomes more attractive when time costs for natural water and waste disposal are factored in.

FOOTNOTES

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[18]Ibid.

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APPENDIX A

February 10, 1983

Dear

Because of your background and interests, we wish to invite you to participate in what we consider to be a significant research program we have initiated. This program is aimed at developing an emperical method to select a best choice water reuse alternative. The method will be tested in the "Valley of Mexico". This area of research has become exceedingly important worldwide because of the many localized water shortages.

To obtain meaningful input from as wide a range of professionals as possible and with the minimum demand on their time, we are using the Delphi Technique as part of our research. For background, we have attached a summary of the Delphi approach we are using and which is oriented toward using a participant's time in the most effective manner.

To form the Delphi panel of experts, this invitation is being sent to individuals such as yourself who represent government, academia, industry and the public.

The questionnaire is directed towards determining the level of importance of certain factors influencing the decision-making process with regard to water reuse. In the Valley of Mexico, water has become a scarce resource because of the rapidly increasing demand and the difficulty for increasing water availability.

The questionnaire is divided into three parts; the first consists of general information about the panel of experts. This data will be used to compare responses by people from different backgrounds, countries and international organizations. The second consists of subjective assignment of level of importance to the factors mentioned and the establishment of best alternative choice regarding each one of the factors. The third consists of any comments that you would consider pertinent.

Your cooperation in completing and returning the questionnaire will be greatly appreciated. Our work depends quite heavily on your assistance. I thank you in advance and look forward to your reply.

Enclosure (questionnaire)

QUESTIONNAIRE

I. General Information

Name: ______________________ Postal Address: ______________________

Telephone Number: ______________ ______________________

____

Place of Employment: ( ) Government ( ) Education ( ) Industry ( ) International Organization

Level of Formal Education: ( ) Bachelors ( ) Masters ( ) Doctoral

II. a) Please rank the pairs of decision factors in water reuse according to their importance using 1 for the most important and 0 for the least important.

FACTORS	ASSIGNMENT OF IMPORTANCE
Public Health Aspects	
Water Quality Requirements	
Water Exchange	
Capital Cost of Treatment System	
Operation and Maintenance Cost	
Legal and Institutional Considerations	
Public Acceptance	

1 = Most Important
0 = Least Important

EXAMPLE : →

Factors	Importance
X	1 0 1
Y	0 1 0
T	1 0 0
Z	0 1 1

b) Please rank the pairs of alternatives for water reuse with respect to the specific decision factor using 1 for a best choice alternative and 0 for a worst choice alternative.

WATER REUSE ALTERNATIVES	Public Health Aspects DECISION FACTOR
Aquaculture	
Domestic (Potable)	
Domestic (Non-Potable)	
Agricultural Irrigation	
Landscape Irrigation	
Industrial	
Groundwater Recharge (Surface Spreading)	
Groundwater Recharge (Direct Injection)	

WATER REUSE ALTERNATIVES	Water Quality Requirements DECISION FACTOR
Aquaculture	
Domestic (Potable)	
Domestic (Non-Potable)	
Agricultural Irrigation	
Landscape Irrigation	
Industrial	
Groundwater Recharge (Surface Spreading)	
Groundwater Recharge (Direct Injection)	

1 = Best Choice
0 = Worst Choice

b) **Please rank the pairs of alternatives for water reuse with respect to the specific decision factor using 1 for a best choice alternative and 0 for a worst choice alternative.**

WATER REUSE ALTERNATIVES	Operation and Maintenance Cost DECISION FACTOR
Aquaculture	
Domestic (Potable)	
Domestic (Non-Potable)	
Agricultural Irrigation	
Landscape Irrigation	
Industrial	
Groundwater Recharge (Surface Spreading)	
Groundwater Recharge (Direct Injection)	

WATER REUSE ALTERNATIVES	Legal and Institutional Considerations DECISION FACTOR
Aquaculture	
Domestic (Potable)	
Domestic (Non-Potable)	
Agricultural Irrigation	
Landscape Irrigation	
Industrial	
Groundwater Recharge (Surface Spreading)	
Groundwater Recharge (Direct Injection)	

1 = Best Choice
0 = Worst Choice

b) Please rank the pairs of alternatives for water reuse with respect to the specific decision factor using 1 for a best choice alternative and 0 for a worst choice alternative.

WATER REUSE ALTERNATIVES	Water Exchange DECISION FACTOR
Aquaculture	
Domestic (Potable)	
Domestic (Non-Potable)	
Agricultural Irrigation	
Landscape Irrigation	
Industrial	
Groundwater Recharge (Surface Spreading)	
Groundwater Recharge (Direct Injection)	

WATER REUSE ALTERNATIVES	Capital Cost of Treatment System DECISION FACTOR
Aquaculture	
Domestic (Potable)	
Domestic (Non-Potable)	
Agricultural Irrigation	
Landscape Irrigation	
Industrial	
Groundwater Recharge (Surface Spreading)	
Groundwater Recharge (Direct Injection)	

1 = Best Choice
0 = Worst Choice

b) Please rank the pairs of alternatives for water reuse with respect to the specific decision factor using 1 for a best choice alternative and 0 for a worst choice alternative.

WATER REUSE ALTERNATIVES	Public Acceptance DECISION FACTOR
Aquaculture	
Domestic (Potable)	
Domestic (Non-Potable)	
Agricultural Irrigation	
Landscape Irrigation	
Industrial	
Groundwater Recharge (Surface Spreading)	
Groundwater Recharge (Direct Injection)	

III. Comments

THE DELPHI APPROACH

The Delphi was developed by the RAND Corporation in the early 1950's. The objective of this methodology is to obtain the most reliable consensus from a panel of experts who represent government, academia, industry and the public. This objective is achieved by a series of intensive questionnaires and controlled opinion feedback. The method is most useful in circumstances when the problem does not lend itself to precise analytical analysis and can benefit from subjective judgement on a collective basis.

The Delphi involves the following steps:

.Identification of a coordinator of the study

.Selection of a panel of experts to participate in the study

.Development of the first round of Delphi questionnaires

.Analysis of first round responses

.Preparation of second round of questionnaires

.Transmission of second round of questionnaires to the panelists

.Analysis of second round responses

.Preparation of a report with the conclusions of the study.

GLOSSARY

Capital Cost of Treatment System is the initial investment for the construction of a wastewater treatment system.

Legal and Institutional Aspects refer to the water law and the administration of water.

Operation and Maintenance Cost is the cost associated with the operation, maintenance and replacement in a wastewater treatment system.

Public Acceptance refers to the attitudes of the community towards the use of reclaimed water.

Public Health Aspects refer to the state of health of a community or a population.

Water Exchange is the substitution of fresh water by reclaimed water.

Water Quality Requirements are the physical, chemical and biological characteristics necessary to serve specific water uses.

APPENDIX B

April 14, 1983

I would like to thank you for your quick response to our water reuse questionnaire and to inform you that the answers have been very helpful as part of our research.

As a follow up questionnaire, we are sending you, your processed response to the first questionnaire and the average response of the panel of experts. The objective of this second questionnaire is to give you the opportunity to reconsider your answers in the light of the group response. Any comments that you consider appropriate would be greatly appreciated.

Your cooperation in completing this questionnaire is of great value to us. I thank you in advance and look forward to your reply.

Sincerely yours,

I. Please review your answers to the first questionnaire as presented in Table 1, in the light of the mean group response. If you believe that any reconsideration has to be made, please indicate the weight that you consider appropriate for that factor.

TABLE 1

Decision Factors	Importance Weights		
	Questionnaire	Group Response	Reconsideration
Public Health Aspects			
Water Quality Requirements			
Water Exchange			
Capital Cost of Treatment System			
Operation and Maintenance Cost			
Legal and Institutional Considerations			
Public Acceptance			

II. Please review your answers to the first questionnaire as presented in Table 2 in the light of the mean group response. If you believe that any reconsideration has to be made, please indicate the weight that you consider appropriate for that water reuse alternative.

Table 2

Decision Factors / Water Reuse Alternatives	Public Health Aspects			Water Quality Requirements			Water Exchange			Capital Cost of Treatment System			Operation And Maintenance Cost			Legal And Institutional Considerations			Public Acceptance		
	Questionnaire Response	Mean Group Response	Reconsideration	Questionnaire Response	Mean Group Response	Reconsideration	Questionnaire Response	Mean Group Response	Reconsideration	Questionnaire Response	Mean Group Response	Reconsideration	Questionnaire Response	Mean Group Response	Reconsideration	Questionnaire Response	Mean Group Response	Reconsideration	Questionnaire Response	Mean Group Response	Reconsideration
Aquaculture																					
Domestic (Potable)																					
Domestic (Non-Potable)																					
Agriculture Irrigation																					
Landscape Irrigation																					
Industrial																					
Groundwater Recharge (Surface Spreading)																					
Ground Water Recharge (Direct Injection)																					
TOTAL																					

Figure 1. Graphic representation of the ranges and means of the importance weights for the water reuse decision factors according to the first round questionnaire. (The higher the weight the more important the factor)

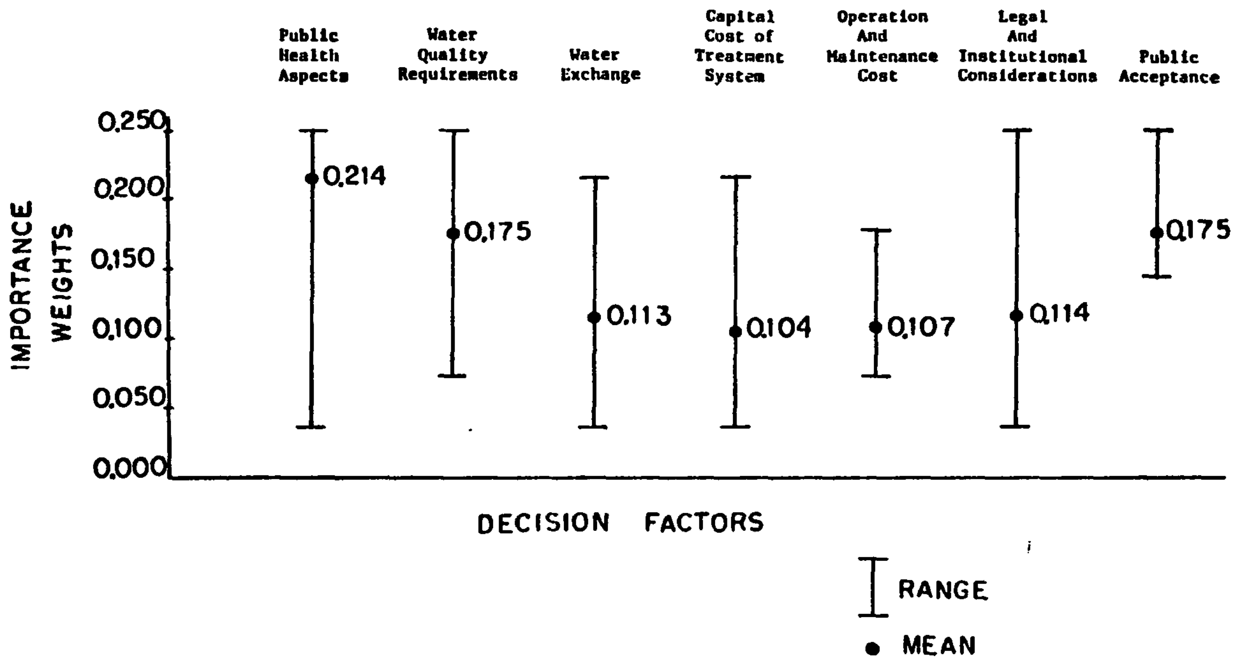
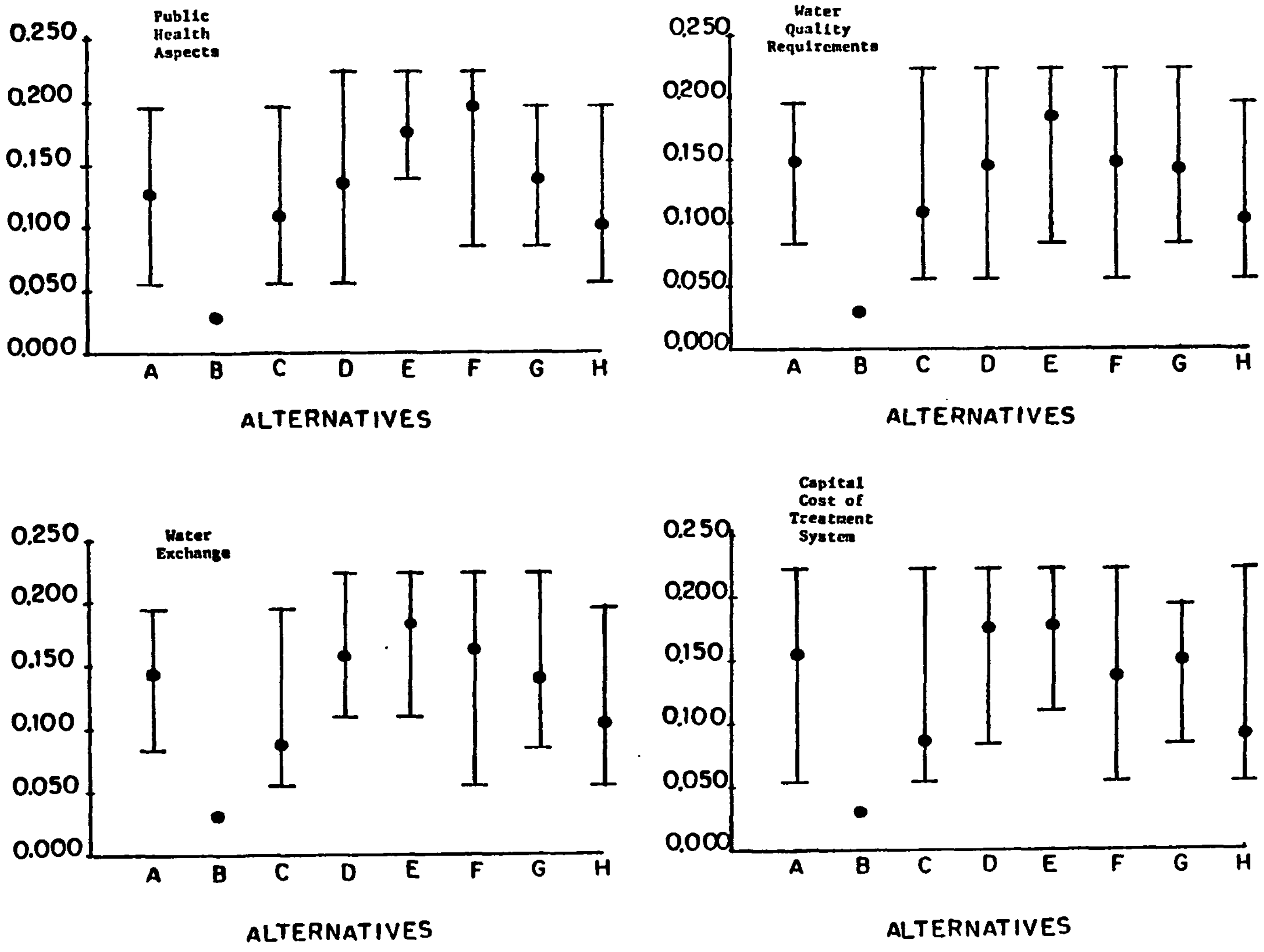
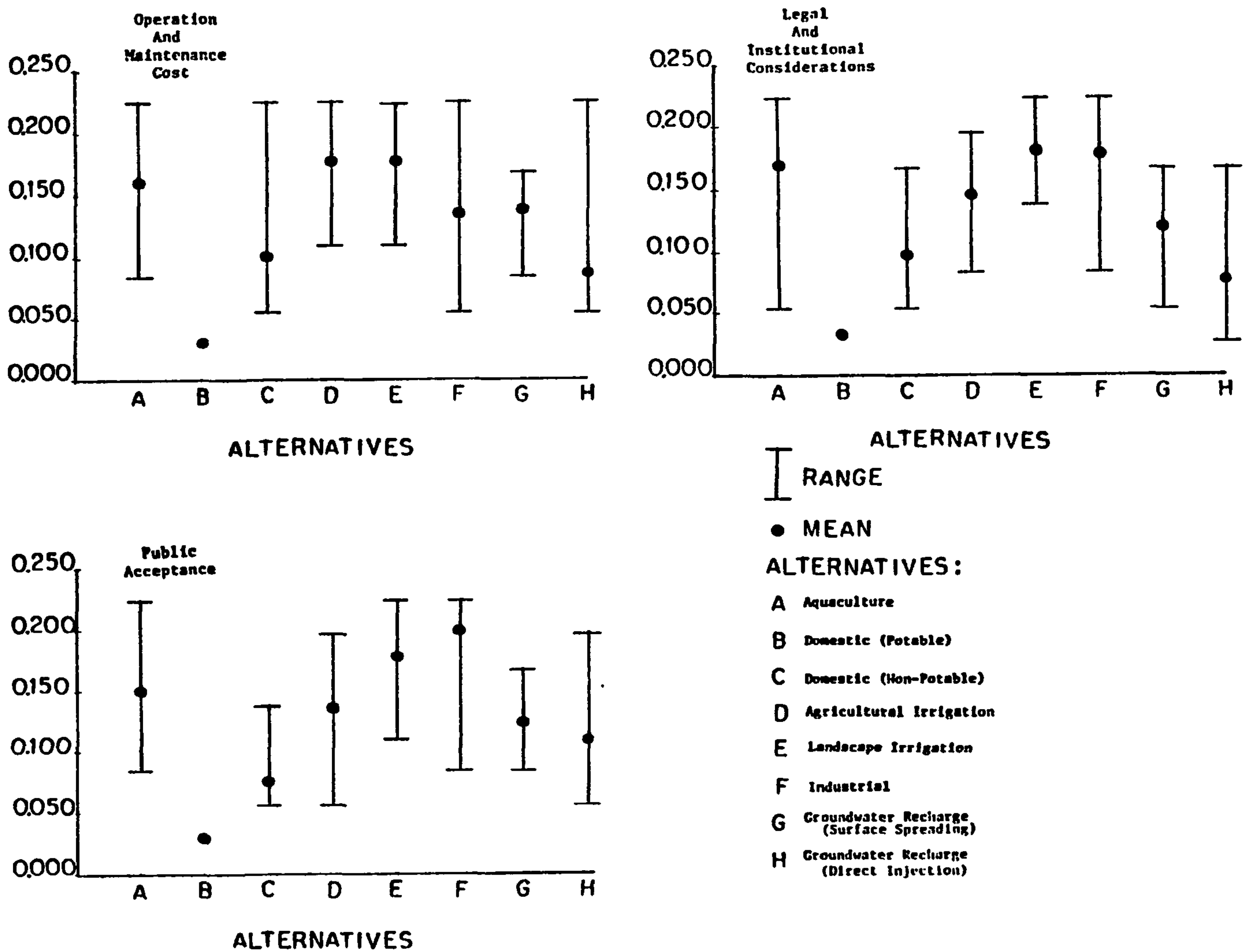


Figure 2. Graphic representation of the ranges and means of the water reuse alternatives according to the first round questionnaire with respect to each decision factor. (The higher the weight the better the choice)




Operation And Maintenance Cost
0.250
0.200
0.150
0.100
0.050
0.000
A B C D E F G H
ALTERNATIVES
Legal And Institutional Considerations
0.250
0.200
0.150
0.100
0.050
0.000
A B C D E F G H
ALTERNATIVES
Public Acceptance
0.250
0.200
0.150
0.100
0.050
0.000
A B C D E F G H
ALTERNATIVES
RANGE
MEAN
ALTERNATIVES:
A Aquaculture
B Domestic (Potable)
C Domestic (Non-Potable)
D Agricultural Irrigation
E Landscape Irrigation
F Industrial
G Groundwater Recharge (Surface Spreading)
H Groundwater Recharge (Direct Injection)

APPENDIX C

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GLOSSARY

Water Use indicates the ways which water is utilized by man in his diverse activities.

Wastewater is any water coming from a previous use.

Reclaimed Water is the wastewater that has been treated to meet a user water quality requirements.

Wastewater Availability is the wastewater that is collected by the drainage system and may be subject to reuse.

Water Reuse is the use of wastewater by a user other than the discharger, after being treated.

Potential Water Reuse is the amount of wastewater that could be utilized by possible water users.

Direct Water Reuse is the planned use of wastewater.

Indirect Water Reuse is the unplanned use of wastewater.

Public Health Aspects refer to the state of health of a community or a population.

Water Quality Requirement are the physical, chemical and biological characterisitics necessary to serve specific water uses.

Water Exchange is the source substitution of fresh water by reclaimed water by the user.

Capital Cost of the Treatment System is the initial investment for the construction of a wastewater treatment system.

Operation and Maintenance Cost is the cost associated with the operation, maintenance and replacement in a wastewater treatmen system.

Legal and Institutional Aspect refer to the water law and the administration of water.

Public Acceptance refers to the attitudes of the community towards the use of reclaimed water.